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against **LIGHT**
POLLUTION? p. 56

This month's
PULLOUT
star charts

February 2009

Astronomy®

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universe apart, from galaxy
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Vol. 37 • Issue 2

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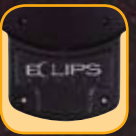
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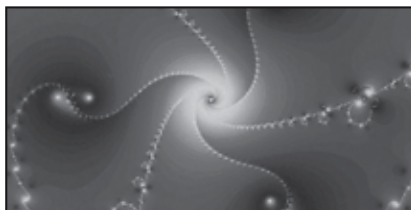
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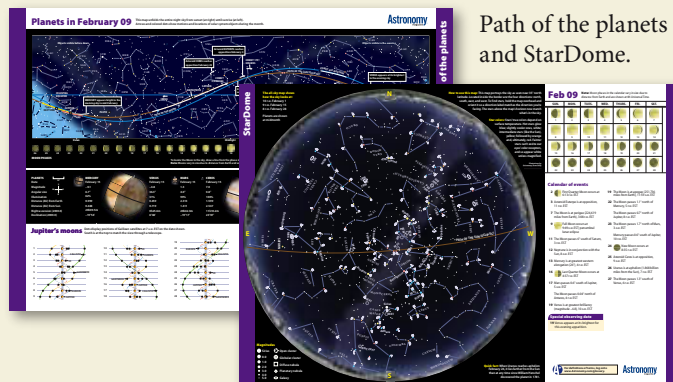
ON THE COVER
Astronomers aren't sure what dark energy is, but they have a few ideas. One possibility leads to a Big Rip — where everything in the universe would eventually rip apart.



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Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Publishing Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187-1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187-1612. Canada Publication Mail Agreement # 40010760.
Cover: *Astronomy*: Roen Kelly; Galaxy photo: NASA and ESA



This Month in Astronomy



The 2008 Out-of-this-World award

by David J. Eicher

Congratulations to the members of the Cincinnati Observatory Center in southwestern Ohio for their win of the 2008 *Astronomy* magazine Out-of-this-World award for public programming by an astronomy group. The \$2,500 award will help the group take its astronomy outreach to the next level. Started in 2006, the annual award recognizes achievements in astronomy outreach and makes possible an expansion of a specific program that will bring astronomy to more people. The project is judged by a group of *Astronomy*'s editors and wisely and energetically overseen by our Online Editor Matt Quandt.

This year's recipient is an organization with a long and distinguished history.

Ormsby M. Mitchel, an astronomer who later became a brigadier general in the Union Army, founded the Cincinnati Observatory in 1842. Former President John Quincy Adams laid the cornerstone in 1843, and the observatory's classic 12-inch refractor has been one of the nation's historic instruments ever since. In 1997, a group of citizens and staff formed the Cincinnati Observatory Center to preserve the historic buildings and promote astronomy in the community. Partners include the University of Cincinnati, the Cincinnati Astronomical Society, and others.

Choosing a winner was difficult. We received nearly 40 submissions from 22 states and 3 countries. Past winners were Celestial North, Inc., in Freeland, Washington (2006); and the Aldrich Astronomical Society in Massachusetts (2007).

The Cincinnati Observatory Center (COC) separated itself from the pack with its "40 Telescopes" program, which will present 40 eight-inch Dobsonian telescopes to local science teachers and high school students. To receive a scope, a teacher or student must submit an essay about how the telescope will be used, go through at least two training sessions with COC staff, and participate in at least two star parties.

"Winning this award puts us well on the road to achieving our goal of getting telescopes to those who will not only use them, but also will conduct outreach themselves," said Dean Regas, COC's outreach astronomer. "*Astronomy* magazine will have helped place 10 superb telescopes with deserving and budding astronomers."

The Out-of-this-World award focuses on ongoing programs by an educational or civic organization. The award recognizes a group's sustained efforts to involve its local community in the science and hobby of astronomy. We'll solicit nominations for the 2009 Out-of-this-World award starting next summer, and we'll keep you posted on how to get involved. In the meantime, congratulations again to the Cincinnati Observatory Center!

Yours truly,

David J. Eicher
Editor



Astronomy

Volume 37, Number 2

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Bright stars hide heart of darkness

Of the 200 globular star clusters in the Milky Way, Omega Centauri (NGC 5139) ranks as the biggest and brightest. It holds some 10 million stars in a sphere roughly 150 light-years across. Unlike most globulars, Omega experienced several generations of star birth. This, combined with its size, suggests Omega is the remnant of a dwarf galaxy that lost its outer stars during an encounter with the Milky Way. This hypothesis recently gained support when astronomers discovered a 40,000-solar-mass black hole at Omega's center. The Hubble Space Telescope took this image, which shows only the cluster's inner third.  NASA/ESA/Hubble Heritage Team (STScI/AURA)







Tour the sky with Astronomy.com

"The Sky this Month" tunes you into the most observable events in the February sky. Search "Community events" to find star parties, lectures, and workshops in your area. Use "Product showcase" to find the latest equipment to get you started in the hobby, including binoculars, telescopes, software, eyepieces, and more.

February web extras

Web extras at www.Astronomy.com/toc bring you additional research, interviews, photographs, and animations that our editors turned up while creating the magazine stories.

"How to make a solar system" p. 28

See a disk gap forming.

"Will dark energy tear the universe apart?" p. 34

Learn about future dark energy experiments.

"Understanding the weirdest stellar explosions" p. 48

Hear more about the light echoes from V838 Monocerotis.

"Ask Astro" p. 54

How many planets are beyond Pluto?

"All about M81 and M82" p. 60

See a gallery of M81 and M82 images.

"The Winter Triangle" p. 68

Explore more Winter Triangle treasures.



M81 (bottom) & M82

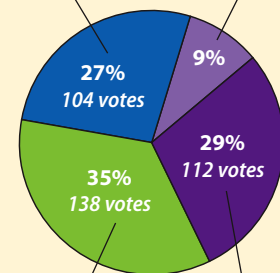
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How closely do you follow current space missions?

I read about them when something makes the news section on Astronomy.com.

I'm more into observing than space exploration.



Total votes: 389

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HOW TO OBSERVE DEEP-SKY OBJECTS

Senior Editor Michael E. Bakich reveals his top 10 deep-sky targets.

Tune us in

Each week, *Astronomy* magazine Senior Editor Michael E. Bakich, a master at explaining how to observe, posts a podcast about three objects or events you can see in the sky. Past observable objects have included:

- **DOUBLE CLUSTER IN PERSEUS**
- **GLOBULAR M2**
- **DOUBLE STAR ALBIREO**
- **SATURN NEBULA**
- **AND MANY MORE!**

This month's top blogs

Editors put their spin on astronomy events in the staff blog. You can share your opinions, too. Read all of the editors' blogs at www.Astronomy.com/blog.

1 ORIONID METEOR VIDEO

Noted astrophotographer and *Astronomy* contributor John Chumack sent us a cool video of the 2008 Orionid meteor shower.

BY KARRI FERRON

2 CHANDRAYAAN-1 NUGGETS FROM JAMES OBERG

India's lunar probe Chandrayaan-1 finally blasted off to the Moon. BY DANIEL PENDICK



Chandrayaan-1 spacecraft

3 ON THE ROAD: ARIZONA SKY VILLAGE

Astronomy magazine Editor David J. Eicher filed reports from his trip to the Arizona Sky Village. BY DAVID J. EICHER

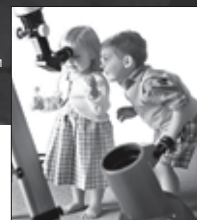


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Omni XLT 120 , 4.7" equatorial refractor	529
NexStar 5SE , 5" go-to Schmidt	799

C10N-GT Advanced , 10" go-to reflector .	\$1229
NexStar 8SE , 8" go-to Schmidt	1399
CPC925 XLT , 9.4" go-to Schmidt	2499
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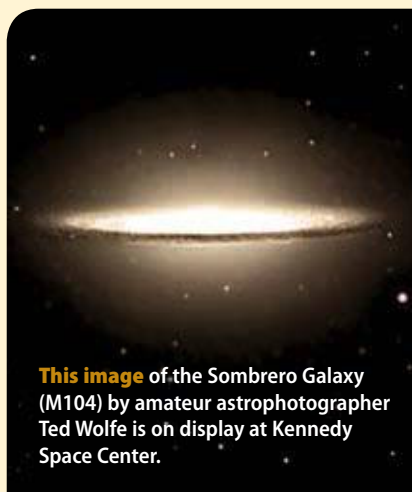


Space images for astro education

Last August, NASA's Kennedy Space Center mounted an exhibit of my images to coincide with the launch of the Hubble repair mission. More than 30 of my color pictures are exhibited at the IMAX Theater as you go into the Space Center; a "Best of Hubble" exhibit is on the other side of the theater. NASA's idea is to show the beauty of space from the professional side (Hubble) and the advanced amateur side (my images). The exhibit will be up through the 2009 "International Year of Astronomy."

Over the last number of years, I have been exhibiting my work in major science museums, universities, and institutions. There are two questions that I feel arise in the minds of today's growing ranks of CCDers:

1. "What else can I do with my 'pretty pictures' other than show them on my web site?" Get out and exhibit them.



This image of the Sombrero Galaxy (M104) by amateur astrophotographer Ted Wolfe is on display at Kennedy Space Center.

2. "Is there a role for the interface between 'pretty pictures' and real science?" They definitely have a role to play in not only educating but also exciting the public about space. This is what the Kennedy Space Center folks see as their role. — **Ted Wolfe**, Naples, Florida

Equipment envy

I want to express my appreciation of your generous space dedicated to contributor photos! I'm sure I'm not the only one who goes for the "eye candy" first in every issue. Lately, I've noticed how many of the photos were taken with setups I can only dream of. I've been wondering what a "Reader Gallery" would look like that's dedicated to sub-\$5,000 setups.

— **Mark Badgy**, Estes Park, Colorado

As photo editor, I choose a celestial object to run in "Reader Gallery" based on its appearance and whether (or, how many times) we've featured the object before.

Regarding equipment, I don't look at the telescope used for the exposure until I'm writing the captions. The truth is that some shots come from astroimagers who have dream setups. But I select lots of

solar, lunar, and planetary images shot through small telescopes, as well.

*Also, we get images from digital cameras, which usually cost less than the average CCD cameras. In addition, I really like (and feature) wide-field images taken with just a camera that show constellations, the Milky Way, planetary conjunctions, auro-
rae, and comets. Just about anyone can take similar shots.* — **Michael E. Bakich**, Senior Editor

Easy understanding

Kudos to Adam Frank for his article "How astronomers cracked the Einstein Code" in the September 2008 issue! Frank took what could have been a weighty, technical, over-the-reader's-head subject and made it fascinating. By sparing the reader the technicalities of Einstein's formulae and the specific computer problems causing incomputability,

he focused on the point of how scientists tackle problems, tirelessly try new approaches, and cooperate within their fields. — **Christina Medlyn**, Rusk, Texas

Calculating a venusian day

In "Taking Venus by storm" (October 2008), the author states on page 68: "The Sun rises in the west and sets in the east, with each sluggish day lasting 117 Earth days." Isn't the correct venusian day 243 Earth days? — **Fred Whitaker**, Littleton, Colorado

The confusion over the length of Venus' day arises because it depends critically on what you mean by a "day." If you define the length of a day as the average time between successive transits of a background star across an observer's meridian (the "sidereal day"), then Venus' day is equal to 243.7 Earth days. Comparatively, the length of a sidereal day on Earth is 23 hours, 56 minutes, and 4 seconds.

*What most people consider to be a day, however, is the average time between successive transits of the Sun across an observer's meridian (or alternatively, the average time between successive sunrises or sunsets). On Earth, this "mean solar day" is the traditional 24 hours. But Venus' slow clockwise rotation causes its sidereal day to be much longer than its mean solar day. Mathematically, Venus revolves approximately 1.60° per Earth day and rotates 1.48° per Earth day in the opposite direction, so they get 3.08° out of phase each day. Because a solar day is how long it takes the two to return to the same orientation (moving through 360°), Venus' day is 117 Earth days long (360°/3.08°). — **Richard Talcott**, Senior Editor*

Correction

In October 2008's "See the final shuttle fireball" (page 22), the last sentence incorrectly identifies the Hubble servicing mission shuttle as Challenger; the correct shuttle is Atlantis. — **Astronomy Editors**

We welcome your comments. Send letters to Astronomy Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.

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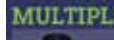
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Strange Universe

by Bob Berman

Betelgeuse: the next banana split?

Surrounded by a shell of potassium gas, this red supergiant could explode soon.

To correctly pronounce Orion's famous shoulder star, "bet" on Betelgeuse. But most Americans instead call it "beetle juice," like the 1988 Michael Keaton film. Either way, it's on the "top 10" list of the most beloved bright stars. It's also one of the few visible from every country in the world. Only the several dozen brave maniacs permanently living at the South Pole never see it.

New research declares Betelgeuse to be the largest of the night's bright stars, edging out its summertime rival, Antares. Its immensity can be grasped with a model: If it were a colossal orange beach ball big enough to enclose a 10-story building — take a moment to picture it — then on that same scale, Earth would be the period at the end of this sentence.

While it's hard to imagine something so immense doing anything but lazily holding court like Jabba the Hut, Betelgeuse rapidly changes size. Breathing in and out like an anesthesiologist's oxygen ball, it speedily mutates from 700 times the diameter of our Sun to a globe 50 percent bigger than that. If our Sun puffed out that much, Jupiter would be its nearest planet, barely skimming above its cool, thin, ill-defined solar surface.

This kind of yo-yo existence is common to all red supergiants living in their AARP years as our universe's stellar senior citizens. Such "lifestyles of the red and bloated" occur because these stars' pressures and temperatures cannot keep up with their core oscillations. It's an epic, unstable contest between outward energy and gravitational collapse — each side briefly winning out in an irregular 3-year period that creates naked-eye brightness variations.

Everything about Betelgeuse is either odd or controversial. Its distance is usually listed as 430 light-years, but last year's newest parallax measurements pushed it

radically out to 640 light-years, which makes its diameter about a thousand times greater than the Sun. The only star with a larger apparent disk is R Doradus, and that's only because it's 3 times closer to us. No surprise Betelgeuse was the very first star to have its diameter measured. The Hubble Space Telescope went further and actually obtained a visible-light image showing an unmistakable disk and blotchy starspots that reveal its rotation. That's quite an accomplishment. Discerning Betelgeuse's $\frac{1}{2}$ of an arcsecond disk is like perceiving detail on a Boston Celtics basketball — from Atlanta.

Betelgeuse is surrounded by a strange shell of potassium gas, like some mineral supplement for a hypochondriac from

Everything about Betelgeuse is either odd or controversial.

the Q-continuum. Blown off the star itself, this element helps form a truly immense bubble extending 300 times farther than Pluto lies from our Sun. Someday, this Betelgeusian homemade potassium may find its way into some new planet's structures, organisms, and maybe even E.T. bananas. Farfetched? Earthly bananas are all made of potassium from a similar, long-gone star. An interesting transition — from red supergiant to banana split.

Every good story requires drama and danger, and in this tale it's Betelgeuse's likelihood of exploding — soon. Although just $\frac{1}{500}$ the age of our Sun, it's actually in its near-death old age thanks to its heavy mass of around 5 million

Earths. This creates such high core pressure that it frantically runs through its fusion fuel as if in a pie-eating contest. It's ready to pop. A dazzling type II supernova could happen anytime. Maybe it already has, with the roiling energy even now headed our way. Its radiation would not destroy our world, but it could influence mutations and alter the course of evolution. Appearing as bright as the Moon, but concentrated intensely as a tiny point, it wouldn't be safe to look at without eye protection. It would cast stark halogen-like shadows and probably make our night sky blue.

How Betelgeuse got its odd name is itself odd. Sourcebooks give wildly different answers. The *Random House Webster's College Dictionary* claims it arose from French taken from Arabic and means "shoulder of the giant." But *Webster's New World College Dictionary*, second edition, says Betelgeuse means "house of the twins." Wikipedia claims the name means "hand of the central one." Everyone says something else.

I think the late George A. Davis, Jr., had it right. The Arabic scholar and Buffalo, New York, amateur astronomer went overseas to original sources to discover the true meaning of various Arabic words. He found the name to be incredibly old, arising even before the Arab desert-dwellers, from the ancient Sumerians, when Orion was visualized as a sheep. Thus, he insisted, Betelgeuse means "armpit of the sheep" — or, to be exact, "armpit of the white-belted sheep." As if sheep wore belts. Well, maybe way back then. Fashions do change, and it would have been better than suspenders.

We can probably agree that "sheep's armpit" is not a very romantic name. So if you want to keep saying "beetle juice," go right ahead. Either way, Betelgeuse will someday get even. ☼

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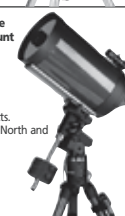
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Winter wreaths

The night sky's "magic circles" tell ancient tales of new beginnings.

Before DVR and DVDs, before radio soap operas, before the printed word, gathering around a fire at night and listening to a loved one spin a tale was part of everyday living. Families and friends relied on this "magic circle" to provide them with nightly entertainment, which helped them forget the troubles of the day and their fears of the night. Like the magic circle of old, the night sky can forge bonds (even if it's just between observers and the stars) and offer us timeless enjoyment.

Many of the brightest stars have myths associated with them and the patterns they form. And sharing these stories with other observers has long been a part of amateur astronomy. But the winter sky is extra special because it offers skywatchers an enchanting view of another kind of magic circle — the Winter Circle of bright starlight, which I like to call the Winter Wreath.

Seven brilliant stars make up the Winter Wreath. Each burns like a colored candle in a great ring that encompasses one-quarter of the sky. In February, these stars dominate the southern sky a few hours after sunset.

Start by finding the brightest Wreath star: molten-white Sirius (magnitude -1.5) in Canis Major the Big Dog. It's the brightest star in the night sky. Moving clockwise from it, the other Wreath stars are sunkiss-yellow Procyon (magnitude 0) in Canis Minor the Little Dog; canary-yellow Pollux (magnitude 1.2) and diamond-white Castor (magnitude 1.6) in Gemini the Twins; saffron Capella (magnitude 0) in Auriga the Charioteer; sunburst-orange Aldebaran (magnitude 0.9) in Taurus the Bull; and blue-crystal Rigel (magnitude 0) in Orion the Hunter.

Seeing the Winter Circle as a wreath is fitting because the wreath is a winter symbol that has astronomical roots dat-



The Pentagon in the constellation Auriga the Charioteer is a wreath inside the Winter Wreath. Both share the bright star Capella (Alpha (α) Aurigae). Capella shines at magnitude 0 and is called **Hoku-lei** in Hawaiian, which means "star wreath." Bill and Sally Fletcher

ing to pagan times. While the ancient Greeks and Romans gave us the tradition of placing a wreath on the heads of winning athletes and other champions, some pagans saw the Sun as the divine victor; each winter they celebrated the Sun's triumph over death.

After the Sun's deep descent into the celestial underworld (the region south of the celestial equator) in late December — a time of darkness and death for those in the Northern Hemisphere — the wheel of the year continues to turn. By February

Eve, it has carried the Sun halfway toward its spring resurrection.

Midwinter celebrations to honor the Sun's anticipated return were widespread through much of Europe. Known as Candlearia or Imbolc in pre-Christian times and Candlemas in Christian times, this "festival of lights" was a time for purification, renewal, and hope as the "dark half" of the year ended. In some celebrations it was customary to wear an evergreen wreath with lighted candles on the head. The wreath represented the circle of life,

while the lighted candles symbolized the breaking of winter's spell and the return of light and life to the world.

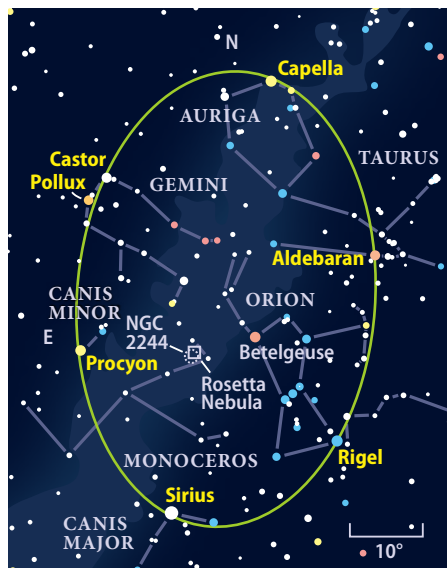
So when you see the seven stellar candles burning brightly in the Winter Wreath this month, think of the longer days, warmer temperatures, and new things in life to come.

Wreaths within the Wreath

Look now at the highest star in the Winter Wreath: Capella, the closest magnitude 0 star to the north celestial pole. Capella is also the brightest star in another winter wreath, one more familiarly known as the 15°-wide Pentagon in Auriga the Charioteer. Indeed, in Hawaii, the name for Capella is Hoku-lei, which means "star wreath." Not only is Capella the brightest star in the lei, but its lofty position and rich yellow hue also embody the exalted status and regal color of Hawaiian royalty.

Similarly, in the Society Islands, the royal temple in Porapora (Borabora) was named Fa'anui in honor of golden Capella and its garland of stars. In this temple, local chiefs were invested with a girdle of yellow feathers that symbolized their greatness.

The poet Alfred Lord Tennyson saw the Pentagon as a funerary wreath. In his dusky 1855 poem *Maud*, in which a man hopelessly tries to contact the dead, Tennyson likens Auriga at winter's end to a



The Winter Wreath, or Winter Circle, is made up of seven bright and colorful stars that cover one-fourth of the night sky. In February, it will be visible in the southern sky a few hours after sunset. *Astronomy: Roen Kelly*



The Rosette Nebula (NGC 2237-9) lies as a smaller, more ghostly laurel near the center of the Winter Wreath in the constellation Monoceros. *Michael Petrasko and Muir Eveden/Adam Block/NOAO/AURA/NSF*

"glorious crown" hanging "Over Orion's grave low down in the west."

Interestingly, near the center of the great Winter Wreath is a smaller, more ghostly laurel: The Rosette Nebula and Cluster in Monoceros. In black-and-white photographs, the pair looks like a large frosted winter wreath surrounding a tiny tombstone of cold starlight.

The cluster (NGC 2244) is quite readily visible to the unaided eye under a dark sky and is a cinch to observe using binoculars. To find it, follow the line of naked-eye stars that extends southwest of 3rd-magnitude Xi (ξ) Geminorum: 15, 13, and 8 Monocerotis. The roughly 5th-magnitude cluster will appear as a hazy nub of light 2° east-northeast of 8 Monocerotis. Through binoculars, the six brightest stars in the cluster form a 30'-long rectangle.

But skilled observers have also spied the wreath's pale, milky nebosity (NGC 2237-9) with binoculars and unaided eyes. If you can't see it, try adding an Ultrahigh Contrast (UHC) filter to either

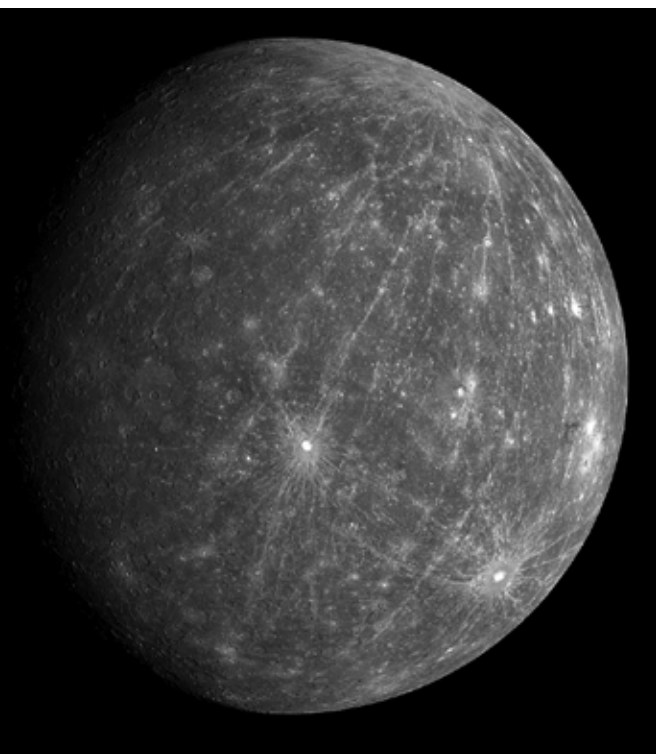
view, and the phantom wreath should mysteriously "rise" from its grave. Give it a try, and let me know how you fare.

But what about Orion's Betelgeuse — the bright, sunburst-orange star burning like a candle near the center of the Winter Wreath? Well, I see it as the cauldron of inspirational fire belonging to Brigit, the Celtic goddess of fire, poetry, and the hearth. Midwinter's Eve was her day. As Charles Squire tells us in his 1905 book, *The Mythology of the British Islands: An Introduction to Celtic Myth, Legend, Poetry, and Romance*: "Brigit was born at sunrise, a house in which she dwelt blazed into flame which reached to heaven; a pillar of fire rose from her head when she took the veil; her breath gave new life to the dead." Inspiration through the goddess on Brigit's Day is the requirement for every new beginning.

Finally, Betelgeuse marks the northeastern corner of the famous Hourglass of Orion — a timely reminder on February eves that the sand in winter's hourglass is running out. ☾

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Backward glance. MESSENGER captured this image of Mercury October 6, some 90 minutes after its closest approach. Most of the terrain in the right half of the image had never been seen by spacecraft. NASA/JHUAPL/CIW

MESSENGER sweeps past Mercury again

Just after 4:40 A.M. EDT October 6, NASA's MESSENGER spacecraft swooped within about 124 miles (200 kilometers) of Mercury's surface. The flyby, the spacecraft's second of the year, revealed about 30 percent of the planet previously unseen by spacecraft — an area larger than South America.

MESSENGER (MERcury Surface, Space ENvironment, GEOchemistry, and Ranging) snapped more than 1,200 photos. It also studied the inner planet's topography, atmosphere, and magnetic field.

One of the biggest surprises came from the spacecraft's laser altimeter, which measures the height of surface features. MIT scientist Maria Zuber says the thin strip examined during this flyby is 30 percent smoother

than the strip seen during the previous flyby in January 2008.

MESSENGER's images of previously unexplored terrain show lots of craters and relatively smooth plains — the same pattern seen elsewhere on the planet. This makes Mercury different from the Moon and Mars, both of which show major differences between hemispheres. The images also reveal lava flows. This volcanic material erupted long ago and now forms a thin blanket over widespread regions.

MESSENGER's September 2009 flyby will set up the spacecraft to enter orbit in March 2011 for a mission scheduled to last 1 Earth year. *Astronomy* will deliver a full report on the recent flyby in its March issue. — **RICHARD TALCOTT**

22 Fermi spots first gamma-only pulsar

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26 Spitzer peeks inside comet

HST back in business

The Hubble Space Telescope snapped a portrait October 27 and 28 of the gravitationally interacting galaxies Arp 147. The craft shot the image just 2 days after recovering from a month of down time. Hubble was functioning well after switching to backup systems to compensate for an earlier equipment failure. Arp 147 is located roughly 400 million light-years away, in the constellation Cetus.

In the portrait, the galaxy at left appears almost undisturbed after barreling through its partner. The right-hand galaxy of the pair appears misshapen and exhibits a blue ring of rapid star formation.

In the same way that a pebble dropped into a pond creates an outward-moving ripple, the collision triggered a shock wave in the blue-ringed galaxy. The shock wave compresses gas, setting off star formation. — **LIZ KRUESI**

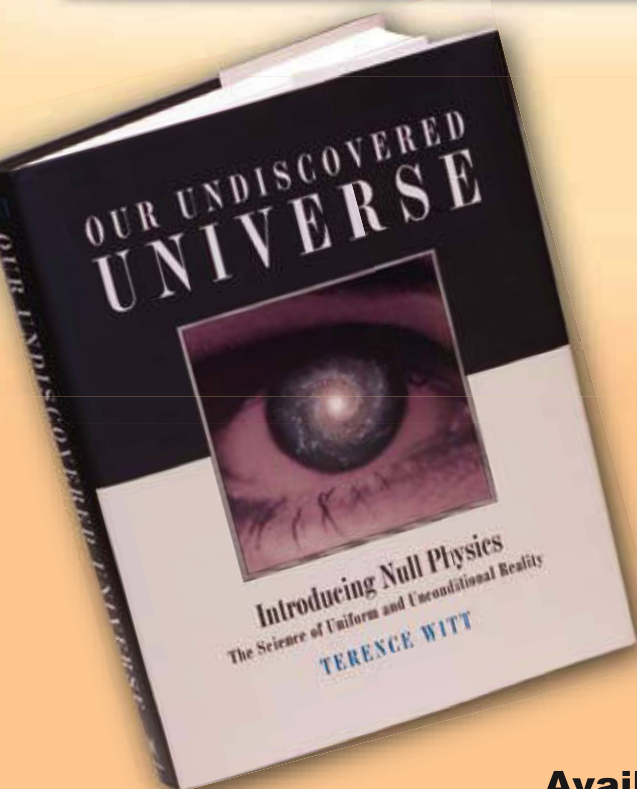


Up and running. The Hubble Space Telescope imaged this galactic duo shortly after recovering from an equipment failure. The left-hand member of the pair is seen nearly edge-on from Earth.

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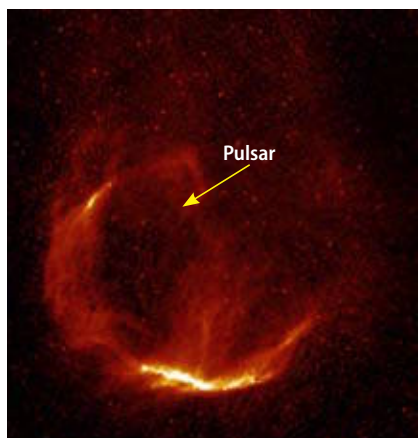
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NASA/S. Pinault (DRAO)

A pulsar's home. Gases in the CTA 1 supernova remnant glow in this radio-wavelength image. Gamma-ray emissions revealed the pulsar's presence to astronomers.

Fermi spots first gamma-only pulsar

The Fermi Gamma-ray Space Telescope has discovered the first pulsar seen to emit only gamma rays. The craft spotted the new pulsar within supernova remnant CTA 1, which lies about 4,600 light-years from Earth. Its rotating beam "blinks" at Earth about 3 times per second, researchers reported online October 16 in *Science Express*.

A pulsar is a rapidly spinning neutron star that radiates energy in concentrated beams. When the energy sweeps past Earth like the beam from a lighthouse, telescopes see a brief pulse.

Astronomers have identified nearly 1,800 pulsars, usually after picking up their radio-energy broadcasts. Theoretical research suggests pulsars emit multiple wavelengths, but we see different ones depending on Earth's orientation.

"Some models predict that the radio beams have a very different size and shape from the gamma-ray beams, with the radio beams being relatively small and the gamma-ray beams being relatively wide," explains Alice Harding, a member of the Fermi team at NASA's Goddard Space Flight Center in Greenbelt, Maryland. With the CTA 1 pulsar, Earth may lie within the strike zone of the wide gamma-ray beam, but the narrower radio beam misses us.

It's also possible that CTA 1 emits only gamma rays, making it detectable to Fermi but not a radio telescope. Discovering and observing more pulsars will help sort out the complex behavior of these cosmic lighthouses. — DANIEL PENDICK

The GOCE satellite goes underground

The European Space Agency's Gravity Field and Steady-State Ocean Circulation (GOCE) mission is scheduled to launch this month after extended delays. Fortunately, the object of GOCE's research — Earth's interior — hasn't moved out of range as mission managers contended with problems associated with the decades-old Russian launch system assigned to carry the probe to orbit.

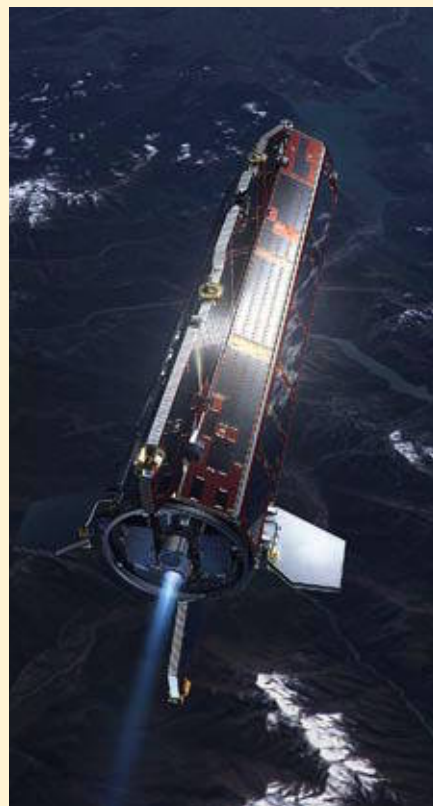
The futuristic arrow-shaped GOCE — resembling a prop from a science fiction film — is about 16.5 feet (5 meters) long. As the craft orbits, it measures tiny variations in Earth's gravity field, which mirror changes in height, density, and temperature of the land and oceans below. Gravity surveys can map the contours of Earth's surface and ocean currents, track motions of underground molten rock, and measure the current rate of sea-level rise due to climate change.

The strength of the gravity variations drops steeply with increasing distance, so the closer GOCE can get to Earth's surface, the better. The craft will follow a relatively low orbit only 155 miles (250 kilometers) above Earth's surface, a height at which it will encounter significant atmospheric drag. An electric ion thruster engine will maintain GOCE's altitude despite the drag.

GOCE pushes the edge of sensor technology as well as the wispy edge of Earth's atmosphere. It packs three ultrasensitive "gradiometers" that measure gravity's pull along three axes. They are so sensitive that GOCE was designed with no moving parts. Otherwise, the motion of even a tiny internal door or lever could be mistaken for a change in Earth's gravity. The sensors can actually measure changes in gravity between different locations in the spacecraft — a first.

GOCE will track ocean currents by measuring the effect on gravity of changes in the temperature or salinity — and therefore the density — of seawater. The satellite can also accurately measure sea-level rise associated with climate change because higher seas mean a slightly stronger pull from gravity on GOCE as it passes overhead.

Past missions have used gravity to probe the interiors of Earth, the Moon, Mars, and



Sun worshipper. GOCE's pole-aligned orbit keeps its solar panels pointed at the Sun, as shown in this artist's concept. The electricity powers the craft's ion engine, which is vital to maintaining a low Earth orbit for collecting gravity data. ESA/AOES Medialab

Venus; asteroids such as Eros and Itokawa; and, most recently, the moons Titan and Phobos. Once proven in practice, GOCE's next-generation gradiometric instruments will become candidates for deeper insights into these worlds and others.

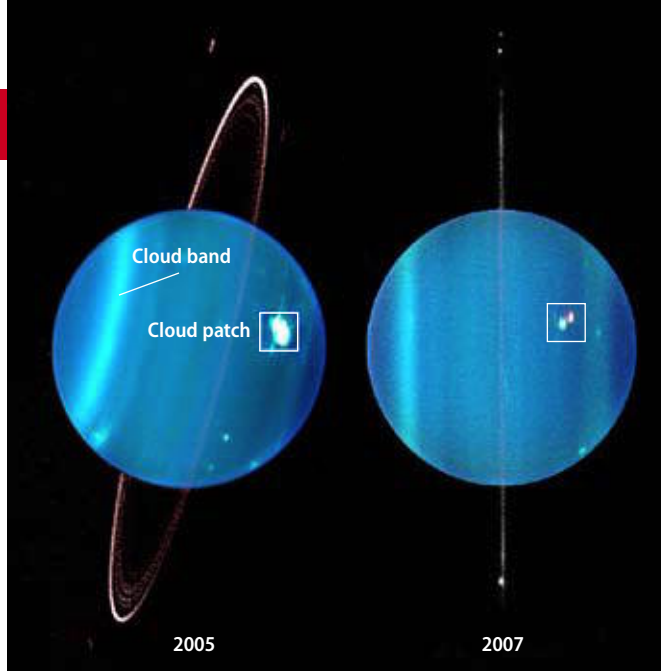
Compared to its advanced instrumentation, GOCE's ride into space seems primitive — and troublesome. The European Space Agency (ESA) contracted with a Russian commercial team to loft GOCE using a military surplus missile, the SS-19 "Stiletto" intercontinental ballistic missile. The addition of an upper stage, called the "Briz" (breeze), converted the former weapon of mass destruction into a peacetime satellite launcher.

The Briz has not been a breeze for the GOCE mission managers, however. Guidance equipment in the upper stage repeatedly malfunctioned during the initial countdown last fall. But with those hardware problems apparently fixed, the latest launch attempt was rescheduled from October 2008 to February 2009. With luck, GOCE will finally go into orbit. — JAMES OBERG

Keck image captures equinox on Uranus

Astronomers unveiled a detailed look at the change of seasons on Uranus. Lawrence Sromovsky of the University of Wisconsin-Madison led the team of scientists that captured the new image in 2007 with the Keck II telescope in Hawaii. "The last time this happened, there were no instruments that could resolve any features on the planet," says Sromovsky, who presented the team's findings October 13 at a meeting of the American Astronomical Society's Division for Planetary Sciences in Ithaca, New York.

The latest Keck image shows Uranus in 2007 as it reached equinox, the time at which the Sun crosses the planet's equator. The equinox occurs every 42 years, which is halfway through Uranus' 84-year orbit.



Change of seasons. The cloud patch visible on Uranus in 2005 (inside box) may be the same one visible in 2007, though smaller and dimmer.

The Keck image highlights detailed features in the planet's pastel blue-green atmosphere, including sharply edged cloud bands. By comparing Keck's 2007 view to future images of the uranian cloud tops, the scientists hope to learn more about the effects of "seasonal forcing," which is the change in solar heating associated with the tilt of the planet on its axis.

In coming years, the Sun's weak light will illuminate more

and more of the northern hemisphere on Uranus. The change in lighting should bring shifts in weather patterns.

Changes already appear to be underway. A bright cloud band visible in the planet's southern hemisphere in a 2005 Keck image appears to be dimming, the scientists say. They predict a similar bright band will develop in the northern hemisphere by the time of Uranus' next equinox. — **D. P.**

Epsilon Eridani sports two asteroid belts

Astronomers reported new similarities between our solar system and Epsilon Eridani, the nearest known planetary system to Earth. Epsilon Eridani's star, located about 10.5 light-years away, is similar in mass to the Sun but about one-fifth its age. The sister system may ultimately provide clues to how our solar system evolved. A team led by Dana Backman of the SETI Institute was scheduled to report its findings January 10 in *The Astrophysical Journal*.

Our solar system's main asteroid belt lies between Mars and Jupiter at a distance of 3 astronomical units (AU), or 3 times the Earth-Sun distance. New observations reveal that Epsilon Eridani also has an inner asteroid belt located at 3 AU, containing the same amount of material as the Sun's main belt. A second asteroid belt lies about 20 AU from the star — approximately the same distance at which Uranus orbits the Sun.

Previous observations showed that the Epsilon Eridani system hosts a third ring of material extend-



More like home. Astronomers discovered that Epsilon Eridani has two asteroid belts, the closer of which lies at the same distance from its star as our solar system's main belt. NASA/JPL-Caltech

ing up to 100 AU from the star. It contains icy debris, comparable to our solar system's Kuiper Belt. The gaps between the two belts and ring suggest the presence of at least three planets.

In 2000, astronomers detected the presence of a possible planet just outside Epsilon Eridani's inner asteroid belt. This leaves at least two other planets as yet undetected, with masses likely to fall between Neptune's and Jupiter's. — **L. K.**

QUICK TAKES

A CARDINAL DISCOVERY

Rob Cardinal at the University of Calgary discovered a comet October 1. It was the second comet in nearly a decade discovered by a Canadian using a domestic telescope.

EXOMARS DELAYED

The European Space Agency has delayed launch of its ExoMars Rover to the Red Planet from 2013 to 2016, pending budget cuts.

JUST DON'T ADD WATER

Engineer Houssam A. Toutanji of the University of Alabama in Huntsville has invented a way to make concrete from just lunar soil and sulfur.

NEW NEW HORIZONS

The National Air and Space Museum installed a model of NASA's New Horizons spacecraft October 17. The actual probe reaches Pluto in 2015.

RUBBLE MOON

Mars Express orbiter images captured in October suggest Mars' moon Phobos is a collection of rubble fragments.

WILSON'S CENTENNIAL

Mount Wilson Observatory, home to a historic 60-inch telescope, celebrated 100 years in December 2008.

HOT YOUNG PLANETS

Researchers reported October 15 that new rocky exoplanets may retain molten surfaces longer, making them easier to detect from Earth.

DIM GRBs DETECTED

Europe's Integral satellite discovered several dim gamma-ray bursts (GRBs), possibly a new sub-type of the usually bright stellar outbursts.

THE PHOENIX SLEEPS

NASA's Phoenix Mars Lander survived a dust storm on the planet in October only to shut down in early November as waning arctic sunlight reduced the probe's electricity supply to a trickle.

SHAKE ON IT

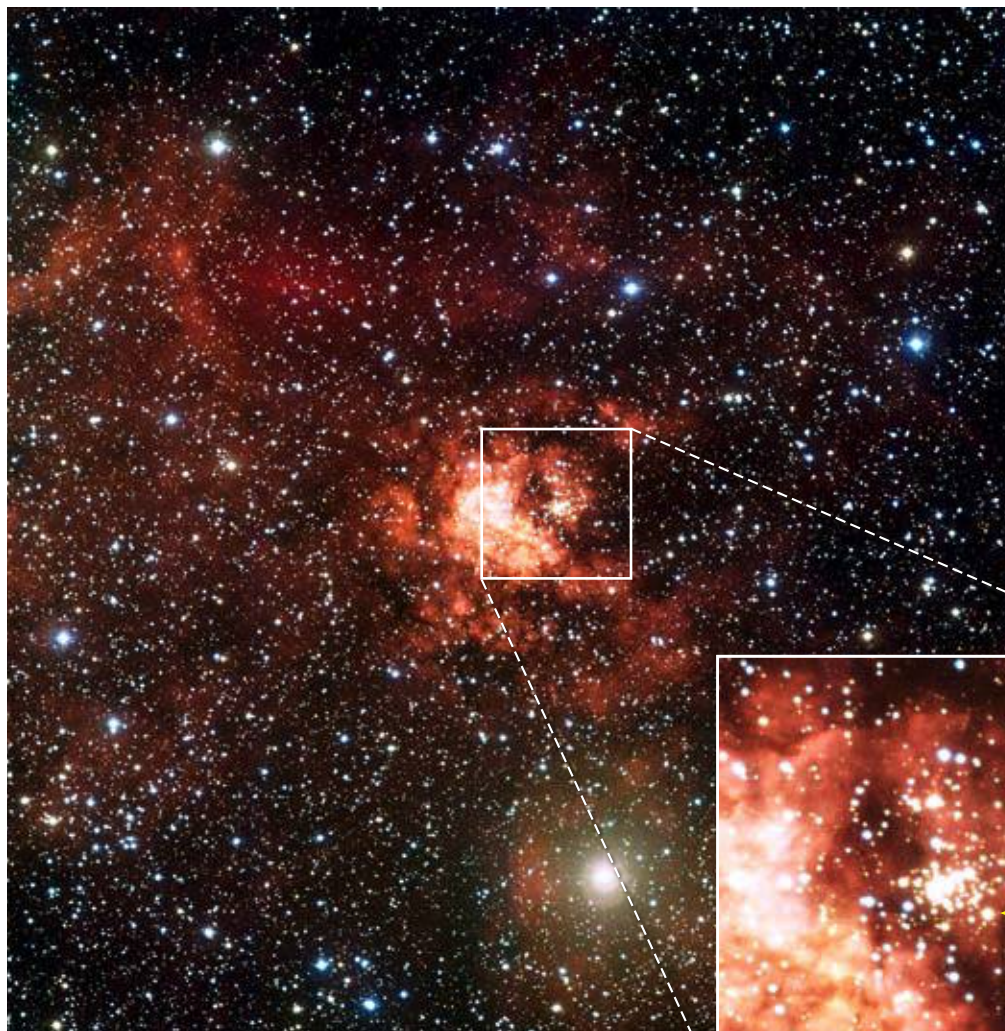
NASA and South Korea signed a statement of intent October 30 to discuss new ways to cooperate in space exploration, Earth science, planetary science, human spaceflight, and aeronautics research.

Gas cloud veils giant star pair

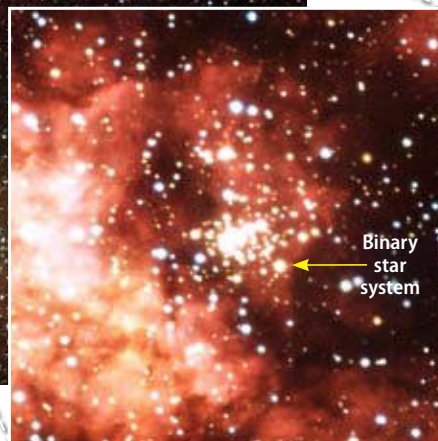
Astronomers have imaged the intricacies of a nebulous region called Gum 29 and its young star cluster. The cluster, known as Westerlund 2, is home to a monster binary star system. The binary stars — one with 82 times the Sun's mass and the other with 83 times the Sun's mass — orbit each other roughly every 3.7 days. These stars are among the most massive known to astronomers.

Gum 29 is located about 26,000 light-years from Earth and spans more than 200 light-years. Intense

radiation from Westerlund 2 sets gas in the nebula aglow. Westerlund 2's stars are relatively young in stellar terms — between 1 and 2 million years old. Astronomers captured the new look at Gum 29 using the European Southern Observatory's 2.2-meter Max Planck Telescope at Chile's La Silla Paranal Observatory. — L. K.



Monster nursery. The gaseous region Gum 29 harbors a young cluster of stars, including the most massive binary pair known. ESO



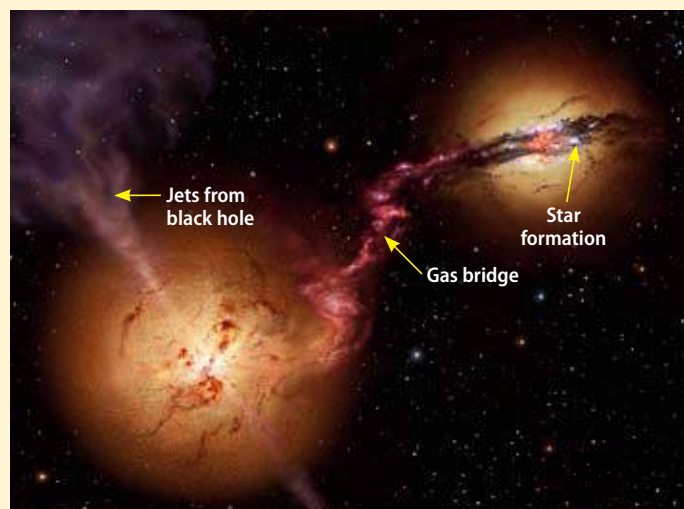
Ancient galaxies mix it up

Astronomers have observed two ancient galaxies in the process of merging where previous observations suggested only one galaxy existed. This new and improved inspection also revealed that both of the massive galaxies host black holes.

Astronomers used multiple telescopes to observe 4C 60.07, an object thought to be a single galaxy with a black hole surrounded by gas undergoing vigorous star formation. The new observations, which appeared November in *Monthly Notices of the Royal Astronomical Society*, show there's more to 4C 60.07 than scientists expected.

One of the galactic pair is emitting strong radio energy as gas spirals down its central black hole. The previously detected star formation is occurring in a nearby companion galaxy. A bridge of gas, torn from the star-forming galaxy, connects the pair.

The scientists believe these two massive galaxies are in the early stages of a merger. The observations show the galaxies as they were almost 12 billion years ago, so by now the galaxies have probably merged completely to form a single massive elliptical galaxy with a central supermassive black hole. — L. K.



Two galaxies in one. Originally considered a lone active galaxy, the object catalogued 4C 60.07 is actually two massive interacting galaxies, as shown in this artist's concept. Council for Science and Technology, United Kingdom



Doug Ellison/unmannedspaceflight.com

India's Moon shot. The Indian lunar probe Chandrayaan-1 orbits the Moon in this artist's concept. The craft carries instruments to perform a wide range of studies.

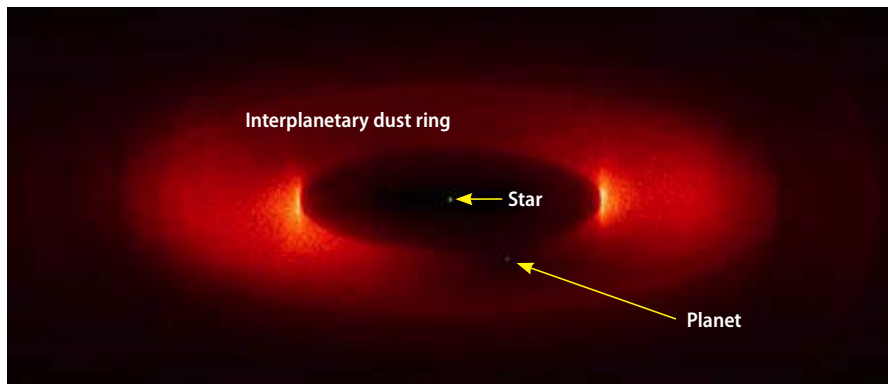
India sends first probe to the Moon

India's Chandrayaan-1 lunar probe blasted off October 22 carrying an international suite of 11 instruments to study the Moon, including two developed by NASA. The lunar orbiter will map the Moon in 3-D, scrutinize the lunar soil, search for signs of water, and measure the abundance of the isotope helium-3, touted as a fuel for future nuclear fusion reactors.

Chandrayaan means "Moon craft" in ancient Sanskrit. The craft carries five instruments designed and developed in India, three instruments from the European Space Agency, one from Bulgaria, and the two U.S. contributions. The probe will remain in an orbit over the lunar poles for 2 years.

One NASA instrument on Chandrayaan-1, the Moon Mineralogy Mapper, will chart the minerals on the entire lunar surface. The other device — the Miniature Synthetic Aperture Radar, or Mini-SAR — will map the permanently shadowed lunar polar regions and possibly locate ice deposits.

The orbiter released an impact probe November 14 that crash-landed in Shackleton Crater at the lunar south pole. India's planned sequel mission, Chandrayaan-2, could carry a rover to the Moon by 2012. — **D. P.**



NASA/Christopher Stark (GSFC)

Planetary dust-up. A planet forms a ring of interplanetary dust in this computer simulation.

Dust rings point to small planets

Astronomers could discover planets around other stars nearly as small as Mars by looking for the clumps and rings they create in interstellar dust. "It may be awhile before we can directly image earthlike planets around other stars, but, before then, we'll be able to detect the rings they carve in interplanetary dust," says Christopher Stark, a physics graduate student at the University of Maryland.

Stark and colleague Marc Kuchner at NASA's Goddard Space Flight Center in Greenbelt, Maryland, described their findings October 10 in *The Astrophysical Journal*.

The researchers developed a mathematical model of 25,000 dust particles — 10 times the number included in previous simulations — orbiting a Sun-like star. The model reproduced the effects of planets ranging from the

mass of Mars to 5 times that of Earth. Stark and Kuchner ran 120 different simulations that varied the size of the dust particles, the planet's mass, and its orbital distance.

As each simulated planet swept through the dust, gravitational interactions created distinctive patterns. In some scenarios, dust clumped up in regions leading and trailing the planet. Planets also induced ringlike patterns and gaps in the dust.

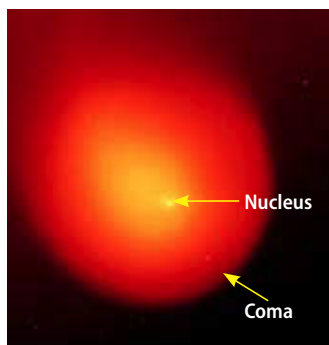
Stark and Kuchner say the simulations suggest that small exoplanets could produce "detectable signatures" even if they orbit relatively far from their parent stars. Observatories that might resolve the patterns include the James Webb Space Telescope, slated for a 2013 launch, and NASA's proposed Terrestrial Planet Finder mission. — **D. P.**

CHINA

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NASA/JPL-Caltech

Inside story. NASA's Spitzer Space Telescope captured this image of Comet Holmes in March 2008.

Spitzer peeks inside comet

After Comet Holmes brightened explosively in October 2007, NASA's Spitzer Space Telescope provided a rare glimpse inside an active comet. A shell of dust obscured Holmes' nucleus, but Spitzer's infrared detectors peered through it. William Reach of Caltech in Pasadena, California, presented the new data on Comet Holmes October 14 at a meeting of the American Astronomical Society's Division of Planetary Sciences in Ithaca, New York.

Spitzer observed the comet in November 2007 and again in February and March 2008. Spitzer's infrared spectrograph probed the chemical recipe of the comet's dusty halo.

In November 2007, the spectrograph data showed that the dust contained many fine particles of silicate minerals, similar in composition to sand. Later, in February 2008, the small particles were gone. "We think the fine silicates are produced in these violent events by the destruction of larger particles originating inside the comet nucleus," Reach says.

The observations show that the fine debris had leaked into space, Reach says. This suggests astronomers may have a relatively brief window of time to study dust liberated during the sudden outburst or brightening of a comet, he notes. — **D. P.**

BRIEFCASE

Beautiful science

The Huntington Library in San Marino, California, opened a permanent 2,800-square-foot exhibit November 1. It showcases some of science's greatest achievements. Titled "Beautiful Science: Ideas that Changed the World," the exhibit highlights four areas of exploration — astronomy, natural history, medicine, and light — and highlights the work of historical scientific luminaries such as Ptolemy, Copernicus, Newton, and Einstein. — **M. M.**

An all-inclusive expedition

In October 2008, American space tourist Richard Garriott enjoyed a paid visit to the International Space Station (ISS) and returned safely aboard a Russian Soyuz capsule. Garriott, the world's sixth space tourist, paid \$30 million for his 10-day adventure. He is a video game creator and the son of former astronaut Owen Garriott, who was a member of the Skylab-3 crew in 1973. — **M. M.**

Extreme planet

Astronomers say the Super Wide Angle Search for Planets (SuperWASP) has discovered the hottest exoplanet known. WASP-12b, a gaseous world 1.5 times the mass of Jupiter, has an estimated surface temperature of 4082° F (2250° C). It's also the speediest exoplanet on record, circling its star once every 1.09 Earth days. — **M. M.**

Good vibrations probe stellar interiors

France's Convection Rotation and planetary Transits (CoRoT) satellite has, for the first time, measured the strength of vibrations on the surfaces of stars other than the Sun. In the same way seismic waves tell scientists about Earth's interior, stellar vibrations can reveal much about the makeup of other stars. Astronomers reported CoRoT's observations October 24 in *Science*.

In a star, some regions contract and heat up, while other areas expand and cool. The interplay of contraction and expansion creates surface

vibrations that cause tiny fluctuations in a star's brightness. The astronomers used CoRoT to observe the fluctuations of three nearby stars.

Scientists determined that the stars' vibrations are about 25 percent weaker than theory predicts. The discrepancy implies that astronomers may need to update theoretical models of how energy flows inside stars.

CoRoT was launched December 2006 with two missions: to observe small brightness fluctuations on stars and to search for exoplanets. — **L. K.**

25 years ago in Astronomy

In *Astronomy's* February 1984 issue, Jeffrey K. Wagner described what planetary geologists were learning from studying meteorites in "The sources of meteorites."

Meteorites are rocks from space that survive passage through Earth's atmosphere and reach the ground.

In 1969, more than 2 tons of extraterrestrial material landed on Earth near Allende, Mexico. The Allende meteorite has yielded many scientific insights, including information about conditions when our solar system was forming.

Planetary geologists studied the Allende space rocks as a dress rehearsal for research on lunar samples slated for collection during the 1969 Apollo 11 mission. "Some researchers might argue that Allende's value to science has been as great as that of the Apollo samples," Wagner wrote.



February 1984



February 1999

10 years ago in Astronomy

Ten years ago, astronomers were preparing for NASA's Mars Climate Orbiter and Mars Polar Lander to arrive at the Red Planet and study the martian surface.

"Divining on Mars," by Michael Carroll, appeared in *Astronomy's* February 1999

issue and described what astronomers were hoping to learn from the probes. "When they reach their destination," Carroll wrote, "Mars Climate Orbiter and Mars Polar Lander will find a desolate planet whose surface is drier than the driest deserts on Earth."

Sadly, neither craft completed its mission. Controllers lost communication with the Mars Polar Lander before it entered Mars' atmosphere. The Mars Climate Orbiter was destroyed while attempting to enter orbit.

It wasn't until 2008 that a probe from Earth finally confirmed the presence of water on Mars. NASA's Phoenix Mars Lander performed that feat by heating a soil sample in one of its onboard laboratories to drive off water vapor. — **MEGAN MCCCHAIN**

Mars crater comes out of hiding

A martian impact crater long buried under tons of ice may have returned to view. The feature, located in vast layered deposits at 83° north latitude, appears as a solitary hill rising partway down an eroding slope. "The mound may be the remnant of a buried impact crater, which is now being exhumed," says planetary scientist Shane Byrne of the University of Arizona's Lunar and Planetary Laboratory.

NASA's Mars Reconnaissance Orbiter discovered the conical mound, which protrudes 130 feet (40 meters) above the slope and consists of polygonal blocks up to 33 feet (10m) across. Reddish dust covers these blocks, which otherwise resemble ice-rich blocks found elsewhere in the layered deposits.

As the layered deposits accumulated to depths of several miles, they buried old impact craters in Mars' north polar region. "But in this rare case," says Byrne, "erosion formed a trough that uncovered one of these structures." He thinks the ice beneath this crater eroded more slowly than the surroundings, exposing the mound as the trough formed. — R. T.

Polar mound. An image captured by the Mars Reconnaissance Orbiter revealed this hill in Mars' north polar region. It may be the remnant of a buried impact crater. NASA/JPL/University of Arizona



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Author, historian



Phil Plait
Bad Astronomy.com



Dave Scott
Apollo 9 & 15



Alan Bean
Apollo 12, artist



Carolyn Shoemaker
Top comet discoverer



David Levy
Author, top amateur astronomer



Gene Cernan
Apollo 10 & 17, last man on the moon



Alan Stern
New Horizons Pluto flyby



Peter Smith
Phoenix-Mars principal investigator

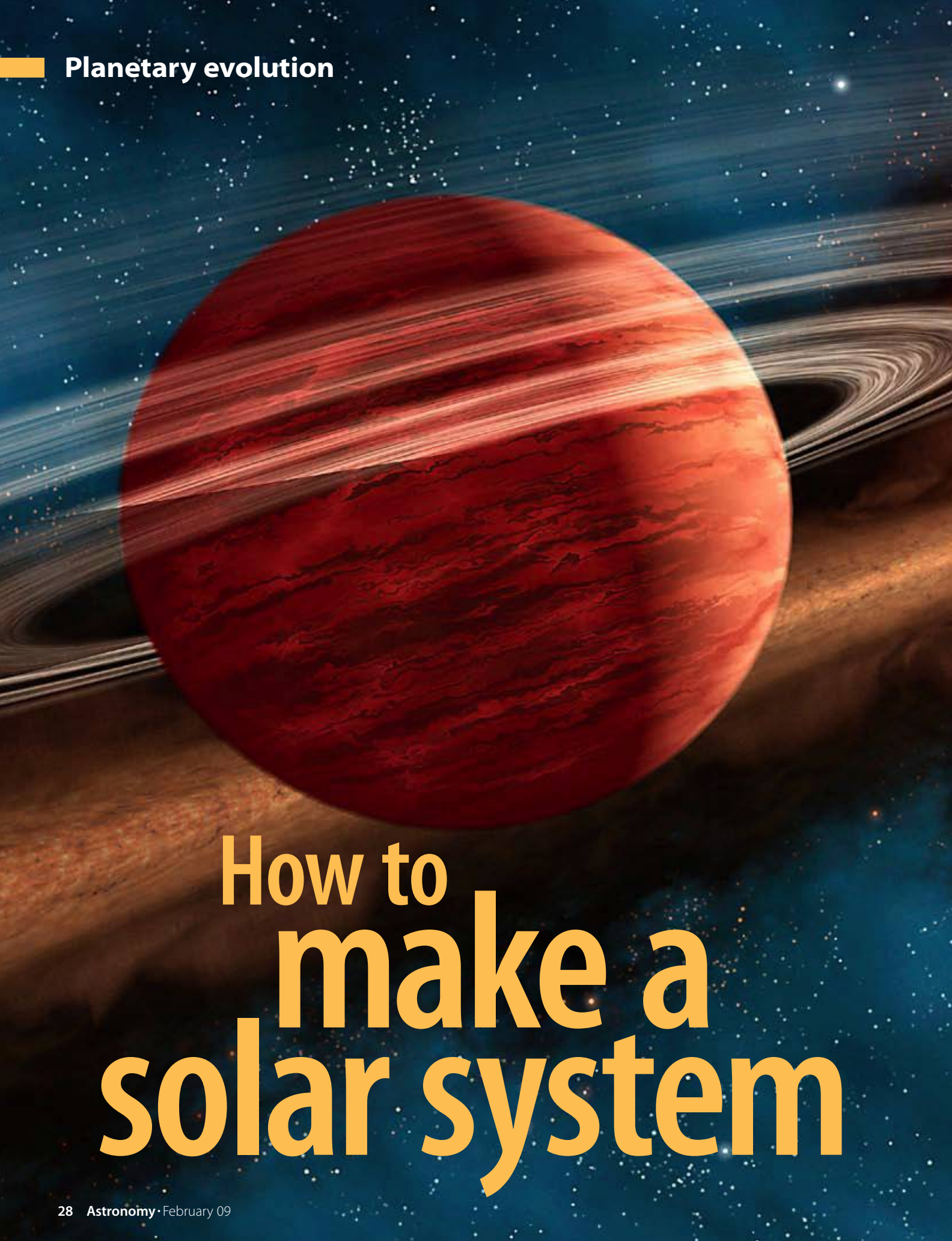


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How to make a solar system



Mysterious gaps in dusty disks around other stars may explain the way our solar system looks. **by Adam Frank**

Astronomers have discovered more than 300 planets orbiting scores of other stars. Many of the new planetary systems look nothing like our own, with its neat division of small inner rocky planets and large outer gas giants. Astronomers have discovered strange beasts like “hot Jupiters” orbiting closer to their stars than Mercury orbits the Sun. Other exoplanets swing around their stars on long, cometlike orbits rather than the nearly circular orbits that rule our own system.

All this diversity in the exoplanetary zoo came as a radical surprise to most astronomers. It left them scratching their heads and struggling with the fundamental question: “Why do they look that way?”

Answering this question demands a return to origins. If astronomers want to know why many exoplanetary systems seem weird by our standards, they need to understand how planets form in the first place. Solving that puzzle has proven difficult because star formation and planet formation are intertwined.

The critical link between young stars and young planets comes in the form of swirling Frisbees of gas and dust

As planets form from disks of dust and gas around a star, they leave clear gaps in their wakes. In this artist's view, a young gas planet has formed a gap in the dusty disk of its birth. The infant solar system's brilliant central star shines in the distance. NASA/JPL-Caltech/R. Hurt (SSC-Caltech)



NASA/C.R. O'Dell (Rice University)

Dense gas and dust in the Orion Nebula (M42) spawns numerous new stars. Peering deep into the famous star-forming region, the Hubble Space Telescope confirmed what theorists had long predicted: Many young stars sport disks of dust and gas (inset) containing the raw material to form planets under the right conditions.

called accretion disks. Thanks to the Spitzer Space Telescope, we have detected planet formation around young stars.

We can't image the planets directly, but we can infer their presence based on the spectral signature of the gaps and holes they carve in their accretion disks. Detecting the disks, coupled with computer modeling studies, provides important insights into the earliest stages of solar system evolution.

Spinning nurseries

Young stars form within vast, turbulent clouds of gas and dust. Throughout

most of the cloud, a tentative balance exists between gravity (which wants to pull the gas in on itself) and pressure (which wants the gas to expand). In some places, however, gravity manages to win the tug of war, and a small chunk of the cloud will begin to collapse. The density and temperature increase at the center of the infalling cloudlet until nuclear fusion ignites a new star.

As the gas falls toward the star, it also starts to spin because of rotation left over from the original cloud's roiling, turbulent motions. Like a twirling skater pulling her arms in to increase her spin,

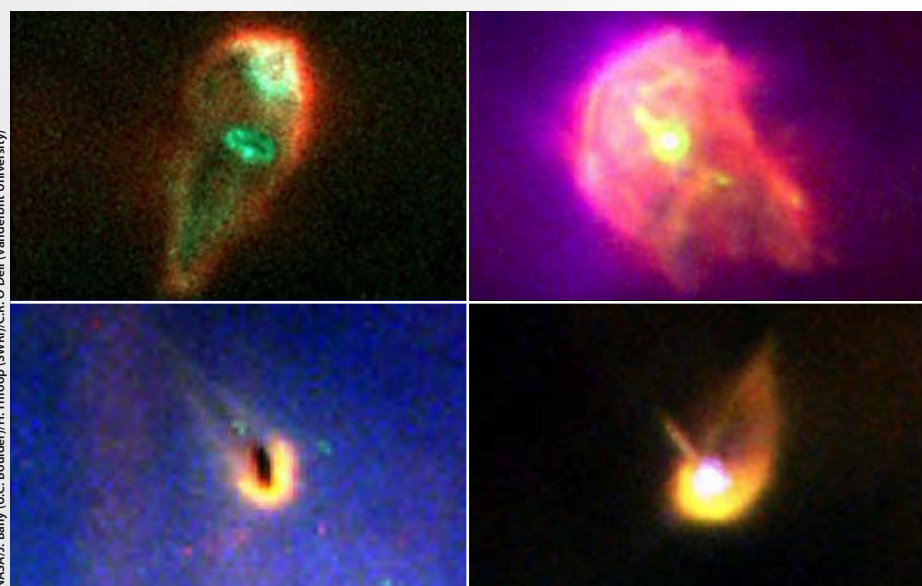
the collapsing gas rotates faster and faster as the cloud contracts. Eventually, the gas rotates so fast that it stops falling inward and settles into orbit around the infant star instead. Because gas along the cloud's spin axis rotates little, it continues to fall toward the center. The result is a disk-shaped mass of gas and dust.

The conditions inside such a disk are just right to build new planets. Dust particles collide to form pebbles, which collide to form rocks, which collide to form boulders, and so on, all the way up to planets. Once the planet is large enough, it begins to exert its influence independently on the disk. This is where my research group at the University of Rochester got started in its work on the dynamics of planet-forming disks.

Making gaps

Peggy Varniere came to work with me at the University of Rochester in 2003 after having recently completed her Ph.D. in France. I had hired her as a research assistant to run supercomputer simulations of dying Sun-like stars, my research specialty. Peggy earned her doctoral degree using an advanced computer code to explore accretion disks around stellar-mass black holes, which form in the collapse of massive stars.

Adam Frank is a professor of astrophysics at the University of Rochester in New York. His article, "How astronomers cracked the Einstein code," appeared in the September 2008 issue.



NASA/J. Bally (U.C. Boulder)/H. Throop (SWRI)/C.R. O'Dell (Vanderbilt University)

Protoplanetary disks grow solar systems only if conditions permit. These four disks, imaged by the Hubble Space Telescope within the Orion Nebula (M42), may be doomed to failure by the blowtorch-like blast of ultraviolet radiation from the nebula's hottest star, Theta¹ Orionis C.

I knew many researchers were working on disk/planet feedback — the dramatic effects a newborn planet can have on its parent disk. I had seen some great talks about this topic at an American Astronomical Society meeting. It would be intriguing if we could play around with these disk/planet interactions, too.

One day after Peggy arrived, I asked her if she could change the conditions in her computer code from a disk around a black hole to one around a young star. Even better, could she drop an orbiting planet into the disk?

Peggy considered the idea for a moment and then responded brightly, “I think I could make it work.” That was the moment our journey into the world of protoplanetary disks began. We had no idea how good our timing would turn out to be.

Astronomers have detected most exoplanets by tracking the slight wobble they induce in their parent stars or by measuring the slight dimming of the star as a planet passes in front of it. Unfortunately, neither of these methods works well for detecting infant planets. To find them, you have to detect the effect of the new planet on the disk of its birth.

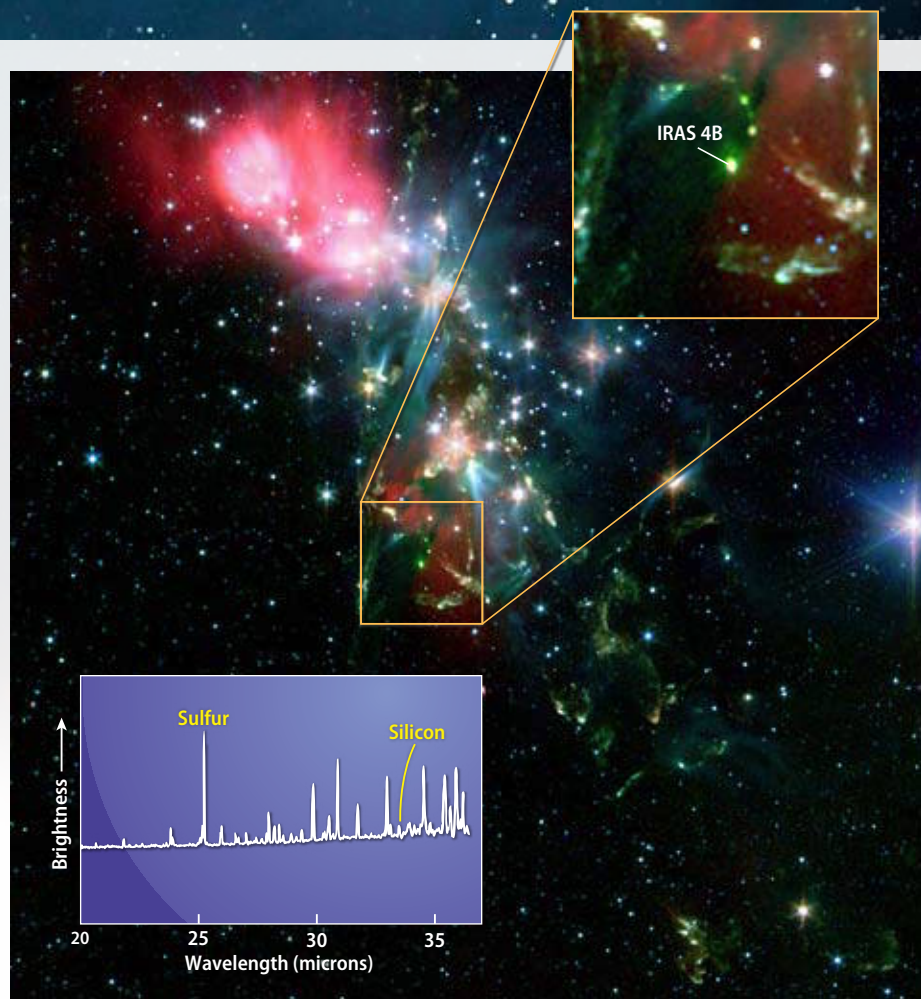
Planet effects

A newly formed planet embedded in a gaseous accretion disk can have a profound effect. Accretion disks don’t rotate as a solid body — like a Frisbee or a compact disk. Gas closer to the center, where the star sits, orbits faster than stuff farther out. That also means the new planet is orbiting slower than disk material inside its orbit and faster than material farther out.

The interplay of a planet’s gravity and the differences in rotation between the planet and the surrounding gas generates strong shock waves that ripple outward. The mismatch in rotation speeds twists the waves into a spiral pattern.

When the planet is born, it is still swimming in disk material. But the “spiral waves” can be strong enough to transport gas away from the planet, much as strong ocean waves heap driftwood onto a beach. If the new planet is big enough, the spiral waves can clear a broad gap in the disk material.

A Jupiter-mass planet at the same distance from its star as Earth from the Sun



The young sun IRAS-4B lies within the star-forming cloud NGC 1333 and sports a dusty protoplanetary disk. Astronomers used the Spitzer Space Telescope to collect infrared light from IRAS-4B and split it up into its component wavelengths, or spectrum. The astronomers found water’s distinctive spectral fingerprint (inset) as well as hints of sulfur and silicon. The water could eventually become part of any new planets forming in the disk. NGC 1333 image: NASA/JPL-Caltech/Harvard-Smithsonian CfA; Illustration: Astronomy: Roen Kelly

would form a gap in its disk stretching from Venus to halfway out to Mars’ orbit. Disk gaps formed by planets are so large they can be detected from Earth. That is good news, because finding a gap means you’ve also found a planet.

Seeing the gaps

Many of the recent discoveries of planet-forming disks come thanks to several of my colleagues at the University of Rochester — namely, Judy Pipher, Dan Watson, and Bill Forrest. In the previous 20 years, they’ve helped to build the world’s most advanced orbiting infrared observatory, the Spitzer Space Telescope.

Infrared light has a longer wavelength than visible light, allowing it to pass unimpeded through dense gas that would be opaque to optical telescopes. Young stars and their disks are surrounded by dense, dusty gas. Thus, the supersensitive infrared detectors my col-

leagues had helped develop for Spitzer were the perfect tools for finding gaps hiding in dusty disks.

Back in 1992, the Hubble Space Telescope had imaged protoplanetary disks. But these stars and any planets they may host are more like adolescents than infants, on the order of 100 million years old. Disks around stars this old contain little more than dusty debris — the leftovers from a planetary construction project completed much earlier.

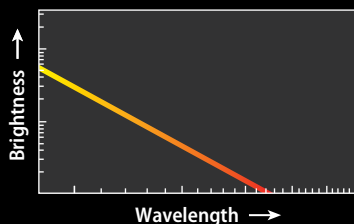
Most young stars — those just a few million years old — with planets recently formed or still under construction, are too distant to image directly with today’s telescopes. To get a good look at these infant systems, astronomers must rely on the indirect method of looking for the spectral signatures of disks and gaps.

Spectra allow us to see how the light from a celestial object divides up by wavelength. The spectral signature of a

Spectral clues reveal gaps in dusty disks

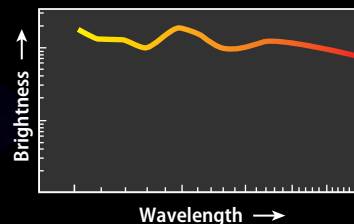
Gaps in protoplanetary disks are too small and distant to image directly. Instead, astronomers analyze the spectrum of infrared light emitted by the star and its planet-forming disk. The spectrum tells astronomers if a star has a disk with a central gap or “doughnut hole.”

Star only



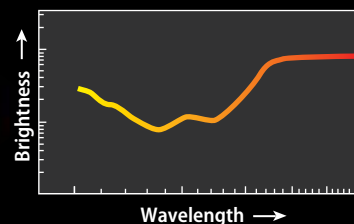
A lone star emits most of its infrared light in the shorter wavelengths located toward the left side of the spectral fingerprint. The longer, “cooler” wavelengths fall off gradually to zero toward the right side of the spectrum.

Star with a continuous disk



The star warms the disk of gas and dust around it, which emits infrared light. The left side of the spectrum contains shorter infrared wavelengths coming from hot dust relatively close to the star. The longer, “cooler” wavelengths toward the spectrum’s right side come from disk material farther from the star.

Disk with a central gap



In a disk with a central gap, the energy emitted by disk material closest to the star is missing, causing the spectral fingerprint’s left side to sag. Gas and dust farther from the star continue to emit infrared, but at the longer wavelengths toward the spectrum’s right side.

young solar system contains information about the young star as well as the disk of gas and dust around it. The star’s contribution is richer in shorter wavelengths — visible light and ultraviolet, for example. The disk emits much more in the infrared portion of the spectrum.

Even though we can’t “see” young protoplanetary disks directly, infrared spectra can tell us what we want to know. Calculations suggested that a continuous dusty disk should appear as a blunt “bump” in a star’s infrared spectrum. The spectral signature of a disk with a gap or a central hole would again look like a bump, but with a small depression or “bite” taken out of it. The bite represents the infrared light missing from the spectrum because of the gap.

The search for gaps

Along with a number of other astronomers, my colleagues at the University of Rochester used Spitzer to collect the spectral signatures of hundreds of young stars, searching for disks and gaps. They got their first bites pretty quickly. After a year or so, they had found at least five

stars that showed the “bump with bite” pattern. More followed.

Astronomers dubbed these objects transitional disks. They represent an intermediate stage between early, gas-rich accretion disks that feed new stars and the dust-only debris disks surrounding older stars. Excitement in the astronomical community grew as additional observations poured in.

Theorists followed close on the heels of the observers. The new, highly detailed data demanded better and more accurate models to explain the physics of transitional disks. My research group decided to jump straight in using Peggy’s modified accretion disk code.

We were lucky to have some keen expertise in-house, including my colleague Alice Quillen, who had done previous theoretical work on debris disks with planets. Alice led the way in the new research, helping Peggy modify her computer code to explore transitional disks. Soon we were watching beautiful simulations of spiral waves from Jupiter-mass planets pushing away disk gas to form a wide gap.

New questions

Our disk-gap simulations meant traveling into new territory. To find the right questions to ask, we pored over papers written by other researchers. We were looking for cracks in what people thought they understood, for unanswered questions on which we could focus our own work.

Soon we found a worthy target: the relationship between a planet’s mass and the properties of the gap it creates. Using Peggy’s computer code, we soon found a direct relationship between the mass of the planet, the size of the gap, and the shape of the walls: Big planets made big gaps with steep walls, and vice versa.

New questions and answers started tumbling out of our work. We examined how the properties of the gap would affect what astronomers saw with current, and even future, telescopes. In that study, we determined that astronomers might be able to directly image disk gaps using the Atacama Large Millimeter/submillimeter Array (ALMA), a giant new radio telescope array under construction in Chile.

Another study helped us understand the behavior of the material sunward of a planetary gap. How long would it take the material to drain onto the central star, transforming an isolated gap into a yawning doughnut hole?

Our initial calculations suggested the process might take hundreds of thousands of years, but subsequent computer modeling showed the inner disk falling onto the star almost 10 times faster. After much work, we tentatively concluded that spiral waves were pushing hard on the inner disk, plowing it into the star.

Gap debates

Each answered question led to new ones, and we knew we were making our small contribution to the understanding of transitional disks. For a scientist, that is where the fun lies. Although we were happily working under the assumption that planet formation creates disk gaps and doughnut holes, not everyone was ready to jump on that bandwagon.

Some scientists, such as Cathie Clarke of the University of Cambridge, have argued that planets have nothing to do with the gaps. She and her colleagues propose that radiation from the central star boils away the disk material. As the disk gas heats up, it evaporates off the disk surface and is lost forever into space.



Planets could form in systems with as many as four stars. This artist's view shows the quadruple star system HD 98800, based on Spitzer Space Telescope observations. A binary pair of stars lies within a planet-forming disk, locked in orbit with a second pair that lacks a disk. NASA/JPL-Caltech/T. Pyle (SSC-Caltech)

Eventually the entire disk dissipates, leaving only the planets that formed and the dusty debris left over from their assembly. Fred Ciesla of the University of Chicago has proposed another possibility, in which turbulence inside the disk gradually depletes dust from the area nearest the star, thus forming a hole.

Another area of uncertainty concerns the relationship between gas and dust in protoplanetary disks. Spitzer's detectors

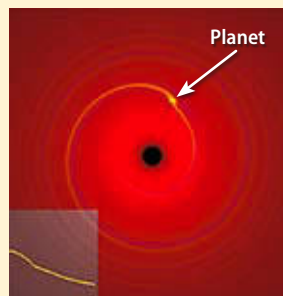
can tell us only about the dust because it, not the gas, emits the infrared light. Astronomers usually assume that, wherever there is dust, there is also a lot more gas. But the only way to test this assumption is with separate observations at wavelengths where the gas emits light, usually in the radio portion of the spectrum. These are difficult observations to carry out. In the meantime, it's possible that the gaps are simply depletions of dust particles, with lots of gas still present.

In spite of these concerns, the consensus among astronomers is that dust and gas do go together and that newly formed planets are the real culprits punching holes in young stellar disks. But it is still too early to say that conclusively. That is just how science works. It's a democracy of ideas until observations can settle the case. New telescopes like ALMA may settle the debate once and for all.

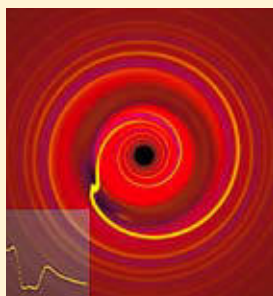
The one thing no one doubts is the importance of transitional disks to the study of star formation and planet formation. Astronomers know that planets must form within the dusty disks surrounding young stars. Despite the wealth of detailed observations of recently discovered transitional disks, the effort to understand them has only just begun. That means a lot more work, and a lot more fun, for all of us astronomers. ☾

How protoplanets create gaps in dusty disks

As a planet sweeps up material from a stellar disk, it forms a clear gap. The images below come from a computer model created by researcher Philip Armitage of the University of Colorado at Boulder. (Images courtesy Philip Armitage)



The simulation begins with a protoplanet of 3 Earth masses following a circular orbit around the central star. As the planet orbits, it generates a spiral wave pattern. The planet has not started to clear a gap in the disk yet, but will do so as its mass grows.



As the planet's mass increases, it saps momentum from gas and dust outside its orbit. The disk material contracts and starts to create a gap. Meanwhile, the planet continues to gather, or "accrete," disk material to itself, growing more massive.



Once the planet's mass exceeds 1 Jupiter mass (318 Earth masses), it is able to clear a large, clean gap. The new planet migrates gradually inward, while maintaining the clear gap around it. Eventually, the gap becomes a hole, as gas migrates toward the star.



See a computer animation of a disk gap forming at www.Astronomy.com/toc.

Will dark energy **TEAR** the universe apart?

Our cosmic fate depends on the biggest unknown in science. by Liz Kruesi

Ten years ago cosmologists made a discovery that shook the world of science: Something is accelerating the universe's rate of expansion. They termed this something "dark energy," but its composition remains unknown. Whatever dark energy is, it dictates the universe's expansion rate and ultimate fate.

If the universe's expansion accelerates at an increasing rate, the energy density associated with dark energy would eventually strip apart gravitationally bound objects. I don't just mean that dark energy would rip galactic superclusters from each other. In this increasingly accelerated expansion, dark energy would rip the Local Group apart, rip Earth from the Sun, and ultimately rip even atoms apart. This violent scenario — the Big Rip — could be the universe's swan song.

The universe's stuff

A plethora of astronomical observations has led cosmologists to more accurately refine the percentage of matter density and energy density (energy per unit volume) in the

universe. The most important of these observations include cosmic microwave background (CMB) experiments, quasar studies, gravitational lensing, galaxy structure surveys, and supernovae studies (see "Cosmology and its crucial observations," page 36).

The fact that the universe is expanding can be traced back to observations by Edwin Hubble and Milton Humason in 1929. In 1998, two separate groups of astrophysicists — one led by Brian Schmidt of the Australian National Observatory and the other directed by Saul Perlmutter of Lawrence Berkeley National Laboratory — discovered that the universe's expansion is accelerating. Both of the findings rely on observational tools called "standard candles."

A standard candle is a type of object that has a certain intrinsic brightness. Therefore, how bright the object appears depends on your distance from it. Think of automobile headlights. You can estimate how far away you are from a car depending on how bright the headlights appear.

Hubble used a type of variable star called a Cepheid as a standard candle to determine the distances to galaxies.



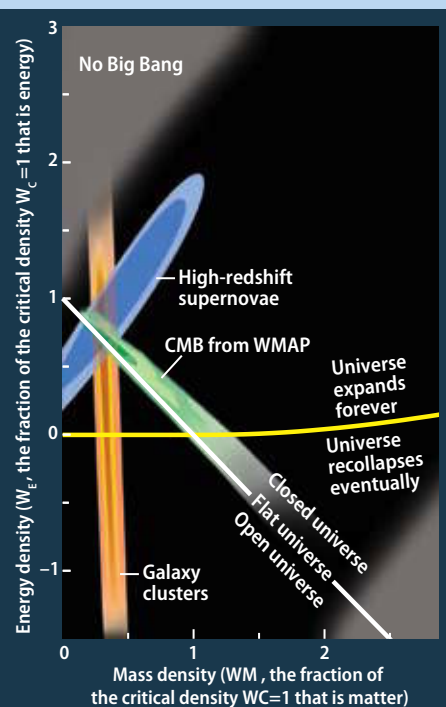
In the future, all galaxies could be ripped apart before the universe's violent end — the Big Rip. Whether the Big Rip occurs depends on what dark energy is. In the Big Rip scenario, after dark energy rips galaxies apart, it would unbind the solar system and tear Earth apart. Eventually, after all gravitationally bound bodies are ripped apart, atoms and particles would follow.

Astronomy: Roen Kelly

Cosmology and its crucial observations

Learning about the composition of our universe has involved multiple astronomical surveys. Below are a collection of the types of observations that have led to astronomers' current understanding of the universe.

- **Gravitational lensing** showed that galaxy clusters must have additional mass that isn't luminous. A massive object — in this case, a cluster of galaxies — can warp space-time. The light from a distant object follows this bent space-time, which allows the observer to see what sits behind the galaxy cluster. The luminous mass in a galaxy cluster is not enough alone to warp space.
- **Galaxy structure surveys** showed that luminous matter (galaxy clusters) clumps in the same way as expected by dark matter simulations. Luminous matter follows the lead of dark matter because of the gravitational force.
- **Type Ia supernovae** observations indicated the universe's expansion is accelerating. Higher redshift type Ia supernovae (those that are further back in time and therefore farther away) are dimmer than expected. Astronomers concluded the supernovae must be even more distant than expected, which means the universe's expansion is increasing.
- **Cosmic microwave background (CMB)** observations first showed in the 1960s that microwave radiation emanates from all directions in space. This observation was evidence for the Big Bang as the universe's beginning. A number of CMB experiments have narrowed down CMB characteristics,



By compiling data from observations of galaxy clusters, the cosmic microwave background, and distant supernovae, cosmologists have gained a better understanding of the universe's components, history, and future.

Astronomy: Ron Kelly, after Saul Perlmutter

but the most recent experiment, the Wilkinson Microwave Anisotropy Probe (WMAP), has been crucial in determining many of the universe's parameters. WMAP, which launched June 2001, has since measured the temperature of the universe (2.725 kelvin), how old it is (13.7 billion years), the percentage of stuff in the universe (4.6 percent normal matter, 23 percent dark matter, 72 percent dark energy; all within 1 percent), and the geometry of the universe (mostly flat).

The period of a Cepheid variable star is related to its luminosity. By observing the period and the brightness of the Cepheid, Hubble could compare the observed brightness with the intrinsic luminosity to determine the distance to the Cepheid.

Knowing only the distance, though, isn't enough to conclude the universe is expanding. Hubble also looked at the spectra of those galaxies and saw that spectral lines were shifted toward the red end of the spectrum. This "redshift" means the object is moving away from the

observer. Hubble compared the distances (obtained via Cepheid observations) with how fast the galaxies appear to be moving away and noticed a direct correlation: The farther away the galaxy, the faster the galaxy moves. The universe is expanding!

Schmidt and Perlmutter's teams used type Ia supernovae — a different sort of standard candle — for their observations. A type Ia supernova originates from a white dwarf star that is part of a binary star system. The white dwarf pulls material from its binary companion, and once the white dwarf reaches a critical mass — 1.4 times that of the Sun — it

begins to collapse. The star doesn't collapse much before the remaining material ignites, and then the star explodes with a fantastically bright blast. Because all type Ia supernovae originate from white dwarfs of the same mass, they all have a similar luminosity.

Both groups observed the light curves from type Ia supernovae and found that the more distant supernovae (which are from an earlier time) were dimmer than expected if the universe was expanding at a constant rate. This means that the distances between those supernovae and the telescopes that observed them are greater than predicted. The universe's expansion has accelerated over time!

So, what is the stuff — dubbed "dark energy" — that's accelerating the expansion rate? This question is one of the biggest facing science today.

Everything that we directly observe — people, stars, interstellar medium — composes only about 4.6 percent of our universe. What about the other 95.4 percent? Through supernova observations and CMB observations, astrophysicists have determined that roughly 23 percent of the universe is something called dark matter and about 72 percent is dark energy. Dark matter interacts via the gravitational force but not the electromagnetic force, meaning scientists know the matter exists, but there's no way to observe it directly. Dark energy is even more bizarre. Most of what astronomers know about dark energy is that it can be any type of uniform negative pressure energy and that it accelerates the universe's expansion.

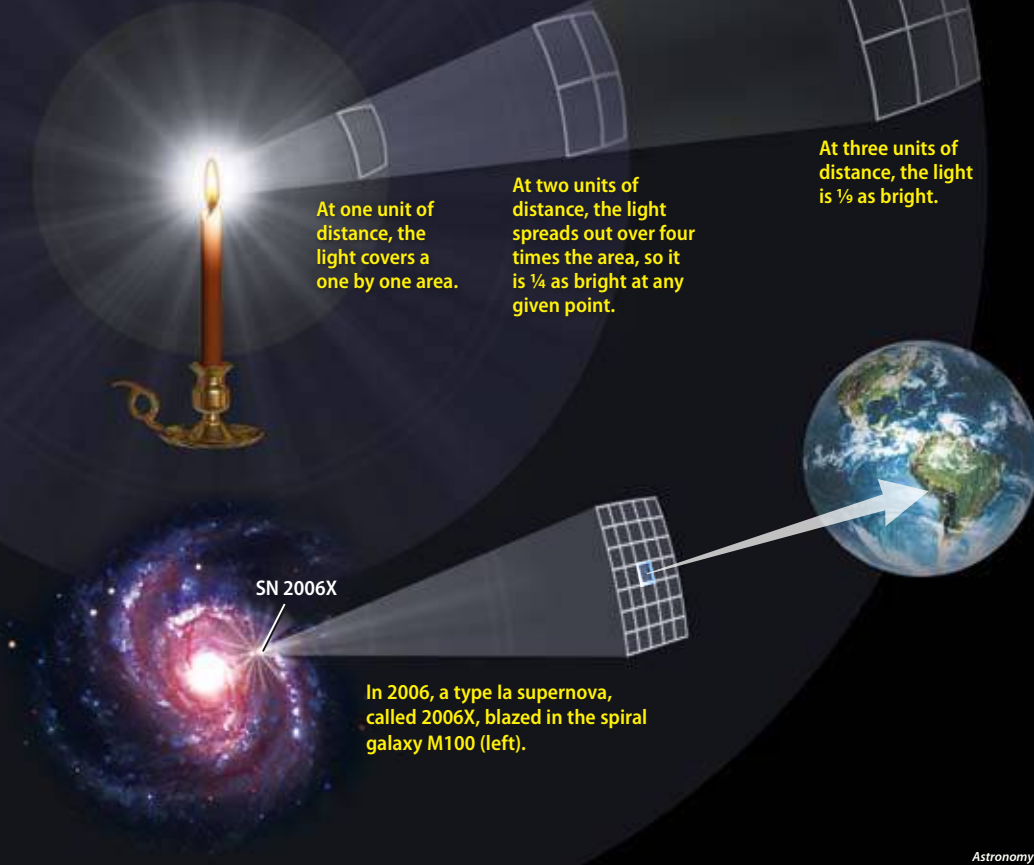
What is dark energy?

Even though cosmologists aren't sure what dark energy is, they have a few ideas. Scientists have three possible dark energy candidates: quintessence, vacuum energy, and phantom energy. Each would result in a different ending to our universe. Which scenario occurs depends both on the value of one parameter and whether that parameter changes in time. This parameter, called the equation of state, w , is the ratio between pressure and energy density (see "The parameter everything hinges on," page 37).

A positive value of the equation of state would cause deceleration in the universe as a result of the gravitational force.

Liz Kruesi is an associate editor of *Astronomy*.

Explaining astronomy's standard candles



◀ As photons beam outward from a light source, they spread out over an ever-greater area. The total light the source produces (its intrinsic brightness) remains constant; but the amount of light an observer sees (the source's apparent brightness) decreases with distance at a predictable rate. As a result, the difference between intrinsic and apparent brightness reveals the observer's distance from the light source.

◀ Astronomers compare a supernova's intrinsic brightness to its brightness as measured from Earth. The difference reveals the distance to the supernova and, therefore, its host galaxy. Scientists have found that more distant supernovae (from an earlier time) are fainter than predicted. This implies that those supernovae are farther away than expected.

Astronomy: Roen Kelly; M100: Las Campanas Observatory/Carlos Contreras

Each dark energy candidate has negative pressure and therefore a negative equation of state parameter. In fact, in order to generate acceleration, the total amount of “stuff” in the universe must

The parameter everything hinges on

The equation of state, w , does not characterize only a dark energy candidate. The following table shows various values for w and what that value represents.

Equation of state value (w)	What that value represents
$w = \frac{1}{3}$	Electromagnetic radiation
$w = 0$	Non-relativistic matter
$w = 1$	Relativistic matter
$w = -1$	Cosmological constant, Λ ; vacuum energy
$-\frac{1}{3} > w > -1$	Quintessence; the value of w can change with time
$w < -1$	Phantom energy

have an equation of state value more negative than $-\frac{1}{3}$. The value also determines how fast the universe expands. And there's more: The equation of state value does not need to remain constant; it can vary in time.

Cosmologists split the dark energy candidates by their equation of state values. Quintessence has a value between $-\frac{1}{3}$ and -1 . It is a dynamic field, meaning its density could change over time or from one place to another in the universe.

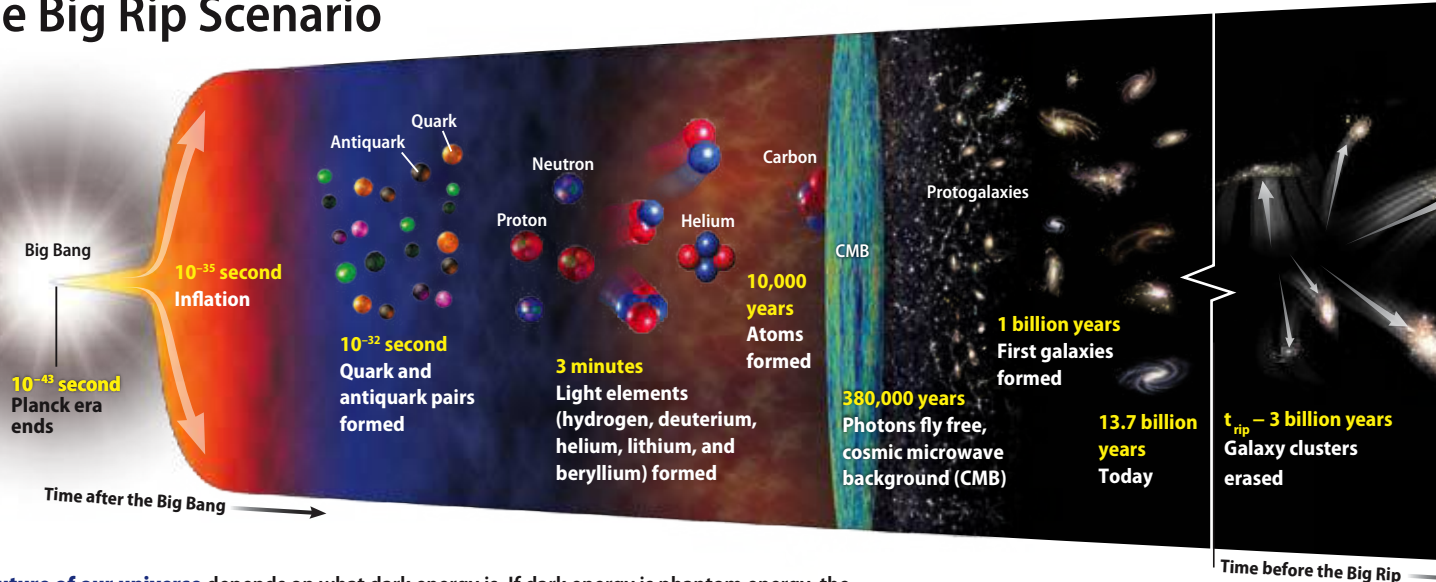
Vacuum energy gets its name from its role as the energy of “empty” space. Space is filled with a smooth energy density of virtual particles (particle-antiparticle pairs) that pop in and out of existence. Vacuum energy can be represented by the cosmological constant term in Albert Einstein's general theory of relativity because both have an equation of state value of -1 and therefore have constant density as the universe expands. Einstein initially coined the term “cosmological constant” to fit into his static universe model. After Hubble discovered the universe is expanding, Einstein retracted the

idea of the cosmological constant, calling it his greatest “blunder.”

While the cosmological constant looks promising as a result of its energy density — an equation of state of -1 closely fits CMB observations — the problem arises when physicists calculate how much vacuum energy is expected in the universe. The standard model of particle physics predicts 10^{120} times more vacuum energy than what scientists observe.

An equation of state parameter more negative than -1 corresponds to phantom energy — the third dark energy candidate. In this scenario, the universe would become progressively more dark-energy-dominated, and acceleration therefore would increase dramatically. So what could this phantom energy be? While vacuum energy comprises virtual particles, “phantom energy might be a perverse type of particle that relaxes by vibrating faster and faster,” says Robert Caldwell of Dartmouth College, lead author of a 2003 *Physical Review Letters* article about phantom energy and its implications for the universe's future.

The Big Rip Scenario



The future of our universe depends on what dark energy is. If dark energy is phantom energy, the universe's accelerated expansion will increase dramatically and lead the universe to a Big Rip. This timeline shows both the universe's past (from observations and computations) and future (if we're heading for a Big Rip). In this case, the equation of state is -1.1 , which places the Big Rip at roughly 86 billion years in the future. *Astronomy: Roen Kelly, after calculations by Robert Caldwell*

In the cosmological constant scenario, the energy density stays constant; in the phantom energy scenario, the energy density increases. Yet one would expect the energy density of dark energy to decrease as the universe expands in the same way a few drops of colored dye dilutes in a tub of water. How do modern cosmological theories argue the energy density stays constant or even increases? Marc Kamionkowski of the California Institute of Technology explains, "Whether the energy density dilutes or not depends on the equation of state of the dark energy."

To further understand this concept, compare a box filled with hot gas to a region of the expanding universe that you observe. (This area is called a "co-moving" region because you as an observer are moving with the region you're observing.) In the box, Kamionkowski explains, "the high pressure associated with the heat may push the walls of the box outward. The heat energy in the box then decreases, but energy is still conserved. The energy lost from the box transfers some energy to the outward motion of the walls. Likewise, in an expanding universe, the change in the energy in a co-moving region of the universe goes toward pushing the adjacent regions of the universe outward."

Recall that the dark energy equation of state is negative; therefore the pressure

is negative, and, says Kamionkowski, "so the energy per co-moving region in the universe actually increases. With a cosmological constant, the energy increase is just large enough to keep the energy density constant, but the energy per co-moving volume is still increasing. Phantom energy

is not too much different, but the energy increase is just a little bigger."

Like all dark energy candidates, phantom energy has not been directly observed, and many questions remain unanswered. But also like the other dark energy possibilities, cosmologists can extrapolate to the universe's future and infer how each dark energy candidate dictates the universe's end.

Our ultimate fate

The poet Robert Frost wrote, "Some say the world will end in fire / Some say in ice." But the universe might hold in store a more violent end. Cosmologists have theorized many ending scenarios to our universe, but its ultimate fate will depend on the behavior of dark energy.

If the dark energy density were to disappear, matter and radiation ultimately would dominate the energy density of the universe. In this scenario — the Big Crunch — the attractive gravitational force would take over, and the universe's contents would collapse into a singularity — likely a black hole. Given what scientists know about dark energy (mainly that it is accelerating the expansion), this Big Crunch scenario is not the most likely ending. However, one can't rule it out.

What if the dark energy density stays constant as the universe expands, as occurs in the cosmological constant scenario? In this situation — the Big Chill — the universe's expansion would continue to accelerate, but the acceleration would not increase. Stars will burn out, galaxies will pass beyond the Hubble distance,

GLOSSARY OF TERMS

Observable universe

The region of the universe that astronomers can observe. It's governed by the finite speed of light and the universe's age: 13.7 billion years. As far as we know, beyond this limit, the universe could be infinite. Many use the term "universe" to mean the observable universe.

Scale factor

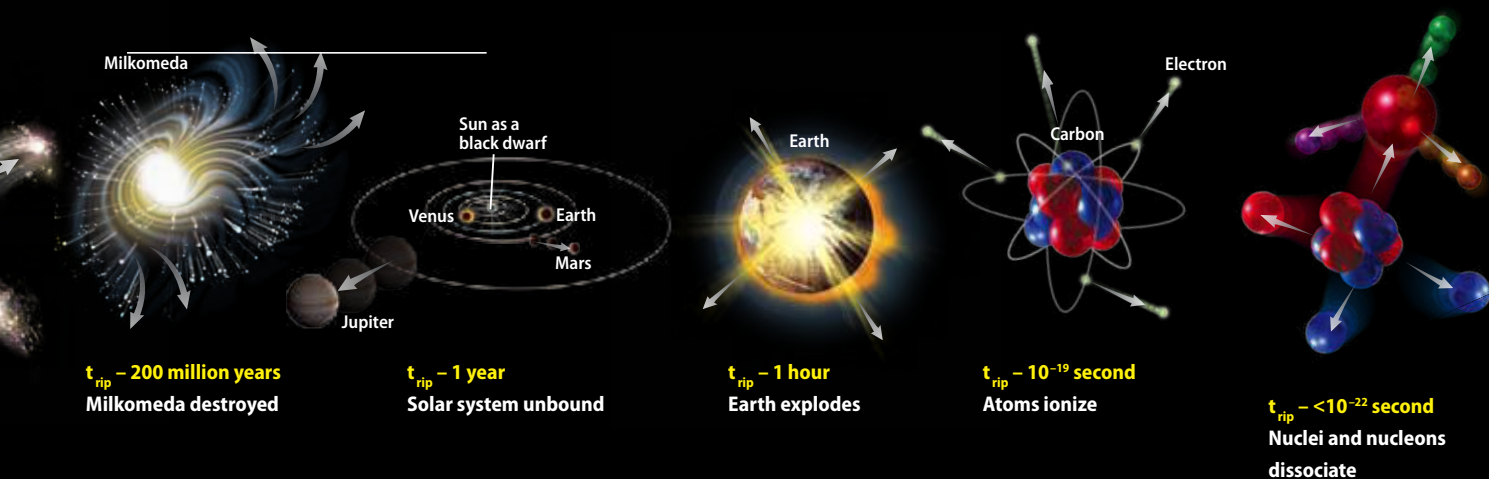
A function of time that represents the relative size of the expanding universe; the current value is 1.

Hubble length

The radius of the observable universe, which is the region of the universe that astronomers can observe.

Singularity

A point at which space and time are extremely distorted; where the curvature of the universe goes to zero or infinity.



About 1 hour
before the end,
phantom energy
will tear
Earth apart.

and space will become empty and cold. The CMB radiation (the radiation that permeates space) will cool to just a fraction of a degree above absolute zero. In the Big Chill, the universe doesn't actually end; it expands forever.

If dark energy is phantom energy, however, we can count on a far more violent end to our universe — the Big Rip.

The Big Rip

Recall that if the equation of state is less than -1 , and dark energy is phantom energy, the universe would become increasingly dark-energy-dominated and the acceleration would increase. When playing out this scenario, the scale factor — the relative expansion of the universe — blows up to infinity. As the scale factor grows larger than the Hubble distance, galaxies disappear beyond the horizon of the observable universe. Similar to the Big Chill, any observers left on Earth would see fewer galaxies. The big difference, however, between the Big Chill and the Big Rip is what occurs next.

Phantom energy will strip apart gravitationally bound objects. Everything in

the universe that is held by the gravitational force will dissociate. The horizon radius shrinks to a point, and all matter will rip apart. First, the Local Group of galaxies will be ripped apart, followed by the Milky Way Galaxy. As phantom dark energy continues to increase, it will rip our planet from the Sun roughly a year before the end of the universe. About 1 hour before the end, phantom energy will tear Earth apart. But it won't stop there.

After all gravitationally bound objects are ripped apart, and just fractions of a second before the end of the universe, phantom energy will rip apart all objects held together via electromagnetic and strong forces. These objects include molecules, atoms, and even subatomic particles. Then the universe will end in a singularity, but a different sort of singularity than the Big Bang and the Big Crunch. In this scenario, instead of all matter and radiation being squashed together, all the universe's components would be ripped apart to infinity.

And that is the Big Rip. It sounds great, doesn't it?

Fortunately, there's no need to worry quite yet. The Big Rip "would not be before [about] 55 billion years in the future, if at all," Caldwell says. Some calculations say it would occur almost 90 billion years from now.

Kamionkowski, co-author of the 2003 article about phantom energy and the Big Rip, explains: "If w is far less than -1 , then the Big Rip occurs relatively soon. If it is extremely close to -1 , but still less

than -1 , then the Big Rip occurs later." The key is to narrow the value of w , the equation of state. "Over the past 5 years, observations have constrained w to be closer to -1 ," he says.

Remember that an equation of state value of -1 corresponds to the cosmological constant. That's how close these two scenarios are. A value of -1 implies a Big Chill, while a value less than -1 leads to a Big Rip. "It could be that the true w takes the value of -1.05 , which is also consistent with current data, and yet it will lead to the Big Rip," explains Dragan Huterer of the University of Michigan.

The possibility of the Big Rip, and when it would occur, teeters on the value of one parameter. Now cosmologists just need to determine that value and whether it holds constant. ▀

T H E B I G R I P

$t_{\text{rip}} = \sim 100 \text{ billion years}$
The Big Rip



Learn about the future detectors that may determine dark energy's w at www.Astronomy.com/toc.

The Sky this Month

Martin Ratcliffe and Alister Ling describe the solar system's changing landscape as it appears in Earth's sky.

February 09

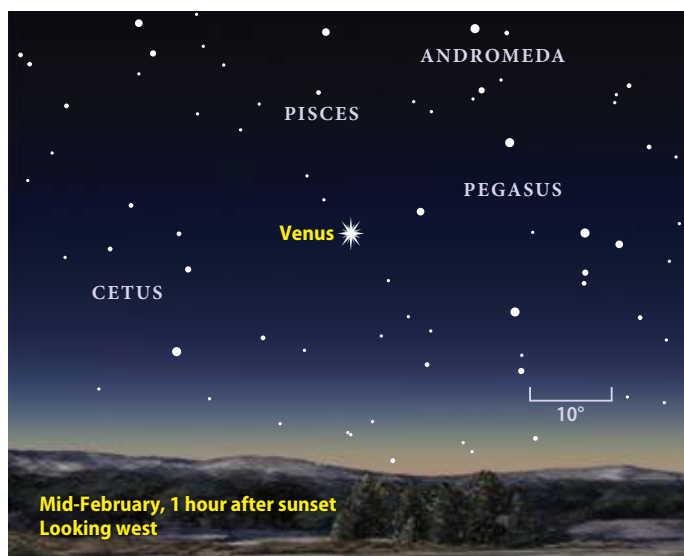
Venus stands high at dusk



The evening star dominates February skies. Venus appears brighter in mid-February than at any other time this year. (In this October 2004 image, Regulus sits next to Venus.) Timothy Ferris

Planet observers will focus on the evening sky this month. Venus plays the lead role as the stunning “evening star,” gleaming

in the western sky after sunset. As the heavens darken and the bright winter stars fill the southern sky, Saturn rises serenely in the east.



Venus stands out in the western sky after sunset this month. It shines so brightly you can see it cast a shadow onto freshly fallen snow. Astronomy: Roen Kelly

40	The evening star rules	  
45	Meteor watch	
45	Rising Moon	
46	When to view the planets	  
46	Titan transits Saturn	
46	Comet search	 
47	Locating asteroids	 
47	See planets line up	  
	 Visible to the naked eye	
	 Visible with binoculars	
	 Visible with a telescope	

Telescopes will show this planet's nearly edge-on rings, which appear wafer-thin.

The morning sky won't impress you nearly as much, although Saturn remains on display until dawn. Otherwise, early risers can try to view a close but challenging conjunction between Mercury and Jupiter during February's final week. Sharp-eyed observers might also spot Mars returning to the morning sky after a long period hidden by the Sun's glare.

The brightest star and the brightest planet both appear well before dark. Sirius, the sky's brightest star at magnitude -1.5 , lies in the southeast shortly after sunset.

Yet even Sirius cannot challenge **Venus**. The brightest planet stands high in the

west, where it shines at magnitude -4.8 . That's 20 times brighter than Sirius.

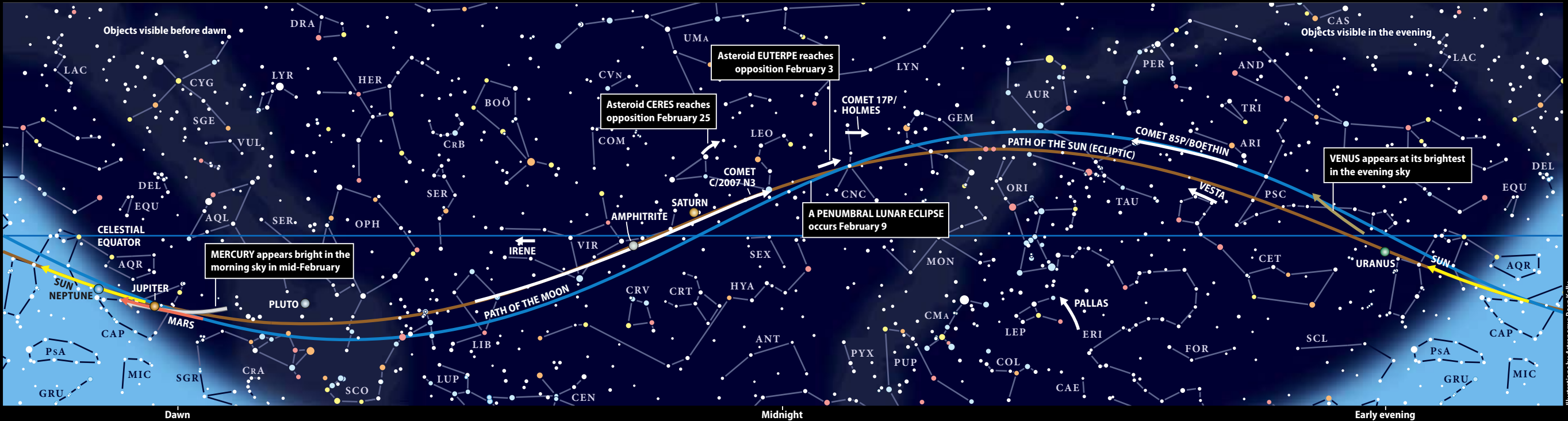
If you follow Venus' position this month, you should notice an interesting pattern. Look at roughly the same time each evening and you'll see Venus standing the same distance above the horizon. (That's why it sets more than 3 hours after the Sun all month.) But gradually, night after night, you'll notice the planet drifting northward.

Venus' angular distance from the Sun remains greater than 40° until February's third week. This keeps its altitude pretty constant. However, the angle between the ecliptic (the apparent path of the Sun and planets across the sky) and the western horizon after sunset

— Continued on page 45

Planets in February 09

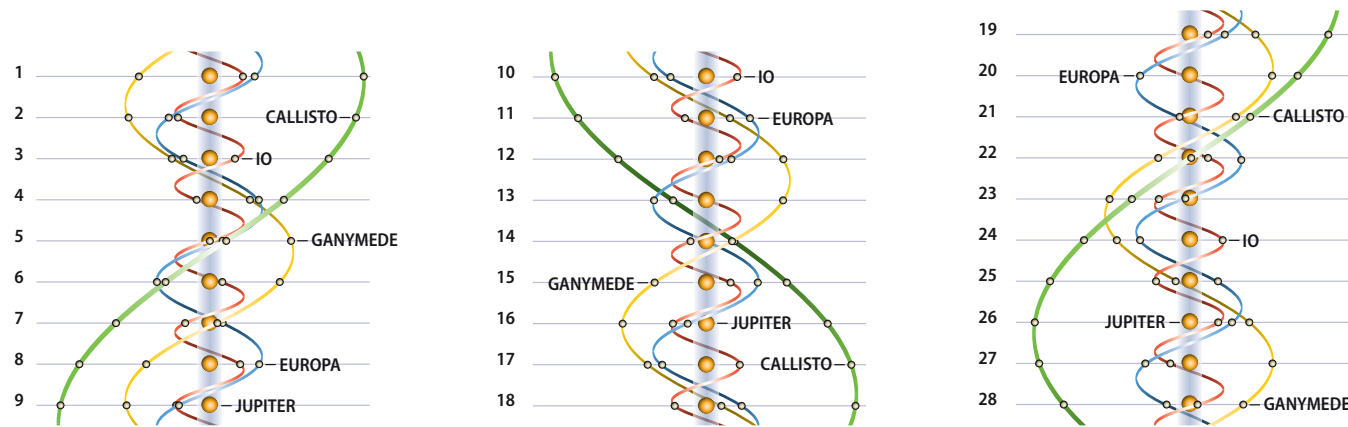
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



PLANETS	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	February 15	February 15	February 15	February 15	February 15	February 15	February 15	February 15	February 15
Magnitude	-0.1	-4.8	1.3	7.0	-1.9	0.7	5.9	8.0	14.0
Angular size	6.7"	36.3"	4.0"	0.8"	32.7"	19.6"	3.4"	2.2"	0.1"
Illumination	62%	31%	99%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.999	0.459	2.313	1.599	6.035	8.467	20.992	31.020	32.170
Distance (AU) from Sun	0.448	0.719	1.411	2.547	5.099	9.380	20.099	30.033	31.599
Right ascension (2000.0)	20h09.5m	0h25.6m	20h42.3m	11h10.2m	20h47.7m	11h26.4m	23h28.2m	21h45.4m	18h10.7m
Declination (2000.0)	-19°54'	6°48'	-19°17'	23°07'	-18°22'	6°03'	-4°14'	-13°53'	-17°44'

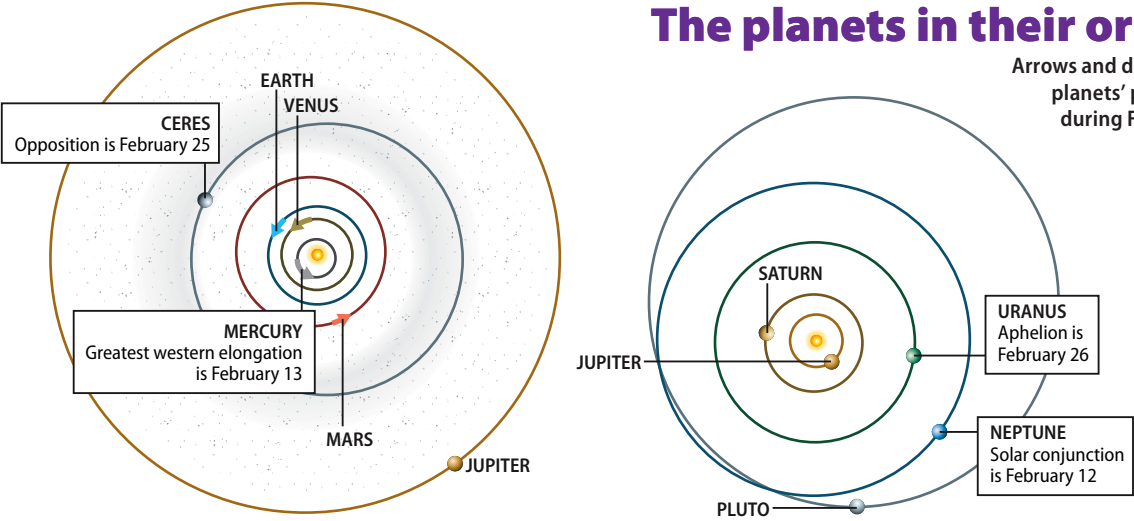
Jupiter's moons

Dots display positions of Galilean satellites at 7 A.M. EST on the date shown. South is at the top to match the view through a telescope.



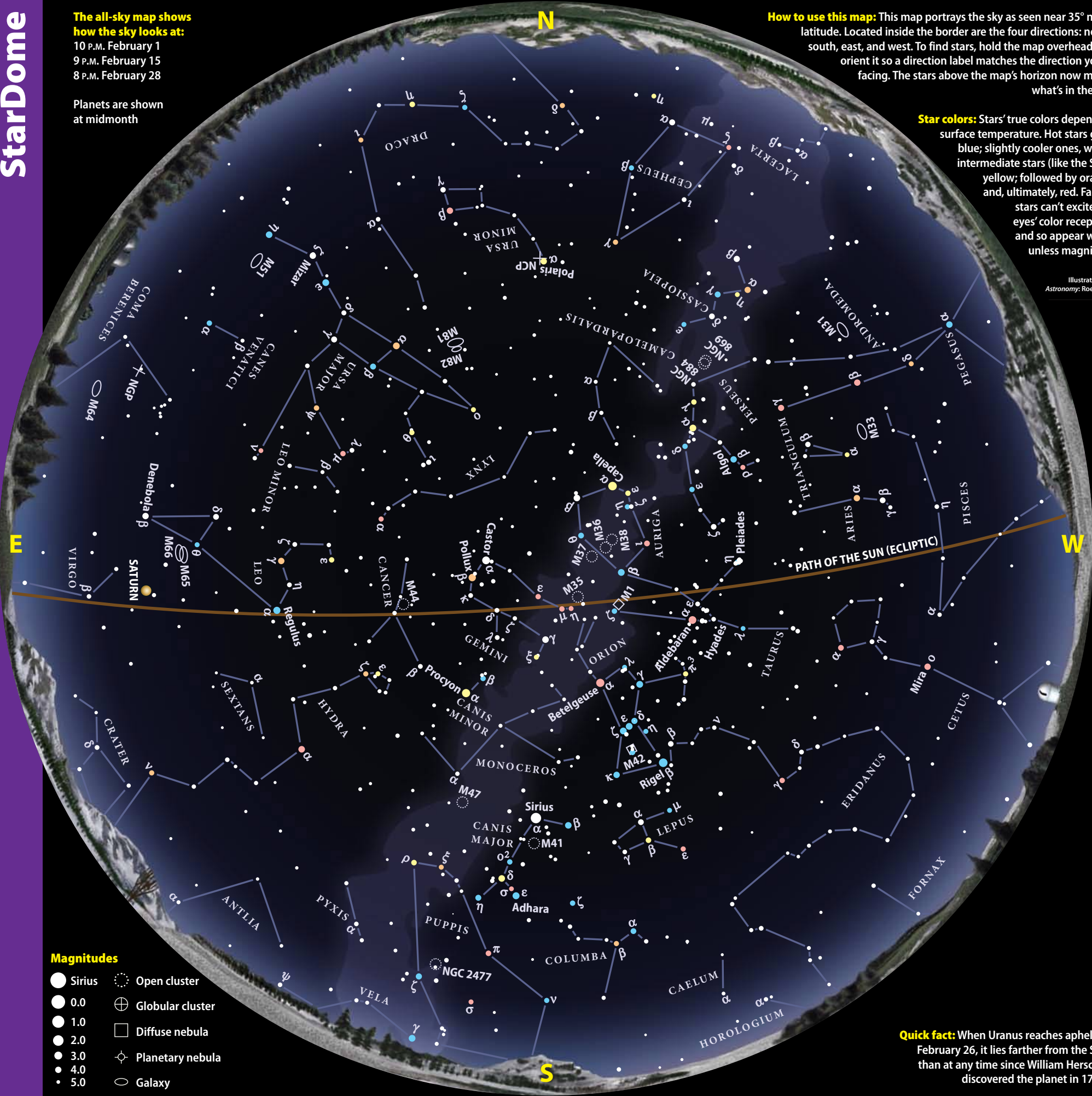
The planets in their orbits

Arrows and dots show planets' positions during February.



The all-sky map shows how the sky looks at:
10 P.M. February 1
9 P.M. February 15
8 P.M. February 28

Planets are shown at midmonth



How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Star colors: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by Astronomy: Roen Kelly

- Magnitudes**
- Sirius
 - 0.0
 - 1.0
 - 2.0
 - 3.0
 - 4.0
 - 5.0
 - Open cluster
 - ⊕ Globular cluster
 - Diffuse nebula
 - ⊛ Planetary nebula
 - Galaxy

Quick fact: When Uranus reaches aphelion February 26, it lies farther from the Sun than at any time since William Herschel discovered the planet in 1781.

Feb 09							Note: Moon phases in the calendar vary in size due to distance from Earth and are shown at 0h Universal Time.
SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.	
 1	 2	 3	 4	 5	 6	 7	
 8	 9	 10	 11	 12	 13	 14	
 15	 16	 17	 18	 19	 20	 21	
 22	 23	 24	 25	 26	 27	 28	

Calendar of events

- 2  First Quarter Moon occurs at 6:13 P.M. EST

3 Asteroid Euterpe is at opposition, 11 P.M. EST

7 The Moon is at perigee (224,619 miles from Earth), 3:08 P.M. EST

9  Full Moon occurs at 9:49 A.M. EST; penumbral lunar eclipse

11 The Moon passes 6° south of Saturn, 3 P.M. EST

12 Neptune is in conjunction with the Sun, 8 A.M. EST

13 Mercury is at greatest western elongation (26°), 4 P.M. EST

16  Last Quarter Moon occurs at 4:37 P.M. EST

17 Mars passes 0.6° south of Jupiter, 5 A.M. EST

The Moon passes 0.04° north of Antares, 4 P.M. EST

19 Venus is at greatest brilliancy (magnitude -4.8), 10 A.M. EST
- 19 The Moon is at apogee (251,736 miles from Earth), 11:59 A.M. EST

22 The Moon passes 1.1° north of Mercury, 5 P.M. EST

The Moon passes 0.7° north of Jupiter, 8 P.M. EST

23 The Moon passes 1.7° north of Mars, 3 A.M. EST

Mercury passes 0.6° south of Jupiter, 10 P.M. EST

24  New Moon occurs at 8:35 P.M. EST

25 Asteroid Ceres is at opposition, 9 A.M. EST

26 Uranus is at aphelion (1.868 billion miles from the Sun), 7 P.M. EST

27 The Moon passes 1.3° south of Venus, 6 P.M. EST

Special observing date

19 Venus appears at its brightest for this evening apparition.

 For definitions of terms, log onto www.Astronomy.com/glossary.

— *Continued from page 40* increases all month. So, as Venus slides eastward along the ecliptic, it appears progressively farther north. It begins February in the southwestern sky, but lies nearly due west by month's end.

A slender crescent Moon hovers less than 2° from Venus February 27. Let their proximity remind you to check out Venus' phase through a telescope. With medium magnification, it's easy to follow the phase as it shrinks rapidly this month. On February 1, you'll find a fat crescent just over 40 percent lit. This dwindles to a slim 20 percent by month's end. Can you spot the nearly 1 percent change each day, or does it take 2 or 3 days to notice?

Combined with this dramatic phase swing comes an equally impressive change in

Martin Ratcliffe provides professional planetarium development for Sky-Skan Inc. in Nashua, New Hampshire. **Alister Ling** is a meteorologist for Environment Canada in Edmonton, Alberta.

Venus' apparent size. As our sister planet pulls closer to Earth, its size swells. On February 1, Venus shows a disk 30" in diameter. By the 28th, its size has ballooned nearly 50 percent, to 44" across.

As Venus descends in the west each evening, look to the east to find **Saturn**. It rises shortly after 8 P.M. local time February 1 and nearly 2 hours earlier by the 28th. At magnitude 0.7, the planet shines almost twice as bright as Regulus, the brightest star in Saturn's host constellation, Leo the Lion. A nearly Full Moon lies near Saturn both February 10 and 11.

Saturn lies almost 800 million miles from Earth. At that distance, its light takes more than an hour to reach us.

The planet's globe appears essentially in full view because the rings tilt nearly edge-on to our line of sight. A thin black line — what's left of the rings' shadow falling on Saturn — bisects the 20"-diameter disk. The rings widen slightly during February. They will continue to do so for the next few months, in a brief respite

Meteor watch



No major meteor shower peaks in February, but keep an eye on the sky and you might witness a brilliant fireball. *Bristen Bourque*

Keep an eye out for February's fireballs

February does not feature any major meteor showers. The general background of sporadic meteors this month runs at a rate of about 7 per hour. Occasionally, these sporadics can be especially bright. If one exceeds the brightness of Venus (around magnitude -4), it qualifies as a "fireball."

Some fireballs leave a glow in the air. These so-called persistent trains can last for a few seconds up to several minutes. If a persistent train lasts long enough, upper atmospheric winds will distort its shape. Although fireballs are rare treats for an individual observer, they occur every night somewhere on the planet. So, while you're out viewing the late-winter sky, keep a watch for these random but spectacular events.

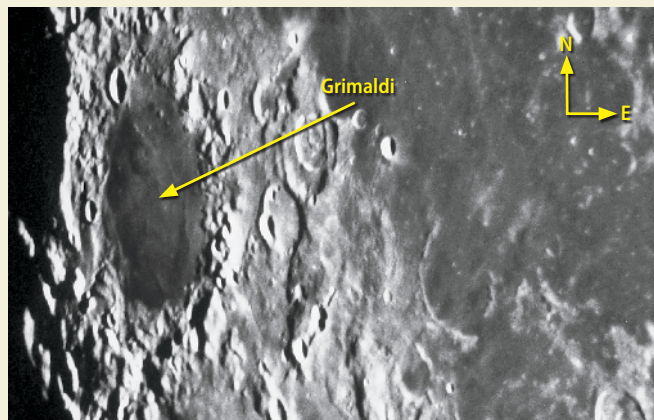
Rising Moon

Conspicuous lunar crater makes good target

The lava-filled crater known as Grimaldi appears conspicuous near the Moon's western limb from just before Full Moon to the approach of New Moon. Grimaldi shows up as the last patch of mare west of the huge Oceanus Procellarum.

Your next opportunity to see Grimaldi comes February 7, when the Sun rises over this feature. The crater's battered rim, stark evidence of its great age, appears ragged from the shadowed pits of smaller craters. As low as the rim is, it will cast long shadows onto Grimaldi's smooth floor at February 7's low Sun angle. One night later, these shadows will have disappeared, but other striking features will have come into view. Look to Grimaldi's northwest for the equally large and battered crater Riccioli. Riccioli presents a much rougher floor than Grimaldi because it was too far from Procellarum's lava floods to get filled up.

Use a dark filter on your eyepiece to reduce the brightness of the nearly Full Moon. If you don't have one, crank up the power to spread out the light, and you'll find it a lot easier on your eye. Note that Grimaldi's floor does not appear uniformly gray. Also, see if you can follow the indistinct rays back to their source — lighter rock ejected from a few major impacts late in the Moon's bombardment.



Dark lava fills Grimaldi, a conspicuous crater located near the Moon's western limb. It shows up nicely just before Full Moon. *Consolidated Lunar Atlas/UA/LPL*

Grimaldi doesn't disappear after Full Moon; it remains visible almost until New Moon. The crater shows up as a sharply defined dark ellipse when the Moon wanes to a thin crescent bathed in earthshine. Look for it the morning of February 22.

When to view the planets

EVENING SKY

Venus (west)
Uranus (west)

MIDNIGHT

Saturn (southeast)

MORNING SKY

Mercury (southeast)
Mars (southeast)
Jupiter (southeast)
Saturn (west)

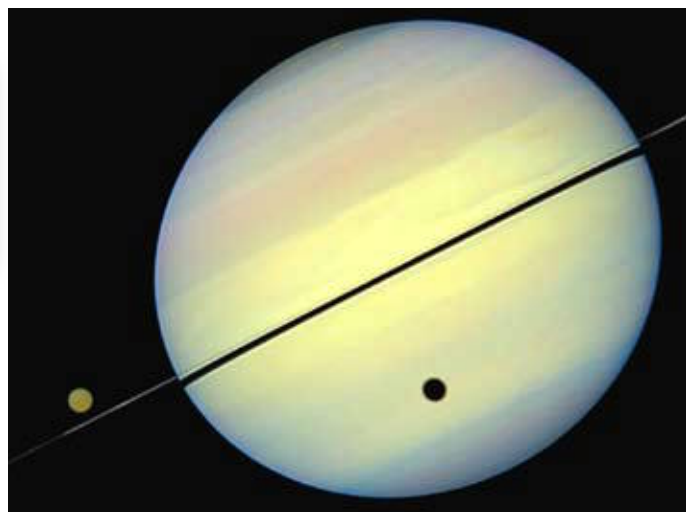
before reversing course. Earth will pass through the ring plane late this summer, an event we won't be able to see because Saturn will then lie behind the Sun.

With Saturn's entire disk now on view, this is an excellent time to look for (and record) subtle features in the planet's atmosphere. White spots occasionally billow up to the cloud tops. Planetary scientists can't predict these spots, however, so it pays to watch for new ones. Saturn's rapid rotation will carry any such feature across the visible disk in about 5 hours. (A full rotation takes slightly more than 10 hours.)

With the glare from Saturn's rings reduced this year, the planet's moons stand out more than normal. Keep an eye out for two particularly intriguing facets of these moons' behaviors.

First, the moons and their shadows now crisscross in front of the planet once each orbit. Titan, the solar system's second largest moon, is the only one that casts a shadow distinct enough to see easily from Earth.

These rare events occur only within several months of a ring-plane crossing. Titan orbits Saturn once every 16 days. Combine this lengthy orbit with the relatively short duration of a



Titan's dark shadow will cross Saturn's disk before dawn February 24. In this 1995 Hubble view, the giant moon lies to the planet's left (above the rings) and the shadow falls at the disk's bottom center. NASA/ESA/E. Karkoschka (UA)

shadow transit — and the fact that the planet remains visible less than 12 hours a day — and you can see why shadow transits don't happen often from any single location.

Observers have only one opportunity this month. On February 24, Titan's shadow crosses the northern part of Saturn's disk just before dawn.

The timing of this event favors observers in North America — particularly those west of the Mississippi River, where the sky will be dark. The shadow will appear starting around 5 A.M. CST (3 A.M. PST). On any other clear night, 8th-magnitude Titan shows up easily through any size telescope.

Comet search

Comet Lulin hits 6th magnitude in Leo

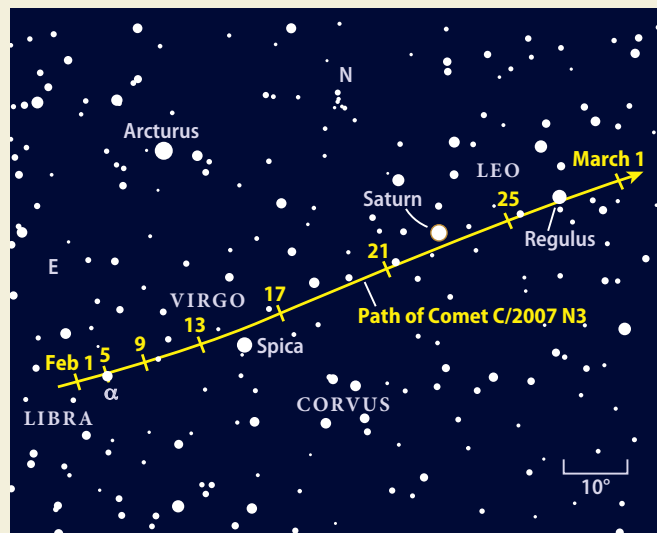
Astronomers predict Comet C/2007 N3 (Lulin) should peak at 6th magnitude or a bit brighter this month. That would make it bright enough to see through binoculars under a suburban sky. And even if it doesn't get quite that bright, it will be an easy target for a scope of any size. Lulin begins February as a morning object but moves into the evening sky within a couple of weeks.

The comet speeds "backward" through the solar system, looping rapidly around the Sun in the opposite direction of the planets' motions. As a result, Lulin appears to move more quickly than most comets. It begins February in Libra, not far from Antares, then passes Spica in Virgo February 15, sits next to Saturn on the 23rd, and hides in the glare of Regulus in Leo by the 27th.

Your first good observing window comes prior to February 7, before the Moon's bright light washes out the sky. The next, and better, window opens after the 15th, when Lulin rises in the east before 11 P.M. Regular readers know that comets look their best under a dark sky, so try to get away from any urban sky glow for a good look.

Lulin lies outside Earth's orbit, so its tail should look fairly short — it streams away from us and doesn't appear broadside. Check for an "anti-tail" pointing toward the Sun around February 26. The comet's dust shroud then lies nearly edge-on from our point of view, giving us a chance to see this uncommon and short-lived feature.

For an extra cometary treat, aim your telescope toward the Pleiades star cluster (M45) February 25. That evening, you can watch the



Comet C/2007 N3 (Lulin) should approach 6th magnitude near the end of February. Follow the fuzzy blob this month as it races westward from Libra to Leo. Astronomy: Roen Kelly

10th-magnitude comet 85P/Boethin glide slowly in front of the famous star cluster. You'll need a dark sky to pick out the comet's faint glow against the star-studded background.

Locating asteroids

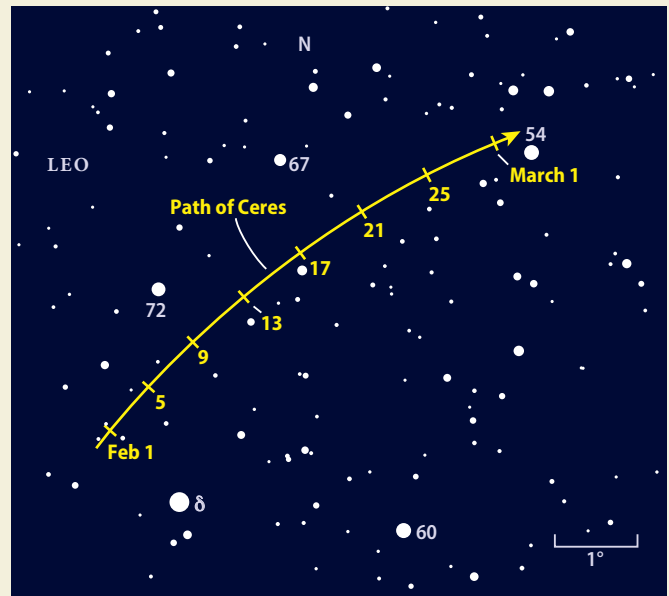
Asteroid Ceres approaches Earth

February is a special occasion for the solar system's biggest asteroid. Not only is 1 Ceres making its closest approach to Earth since 1857, but it also will not get this close again for at least another millennium.

The long-term gravitational tugs of the planets conspire to modify Ceres' orbit just enough for this month's record-breaking event. Still, the difference between the asteroid's appearance now and at other favorable oppositions isn't huge. In 9 years, Ceres will be only 1.2 percent farther away.

You can follow Ceres through binoculars from your backyard. It sails through northern Leo during February, in a region without a lot of bright stars. Simply use the finder chart to pick out the pattern of nearby stars, then look for the interloper.

You may think this close approach will give you a chance to see Ceres without optical aid. You'd be right — although not by much. At opposition, Ceres glows at magnitude 6.9 in a sparse starfield. Sharp-eyed observers under the darkest skies have seen objects this faint before. However, you'll have a better chance just 3 years from now. Ceres will then brighten to magnitude 6.7 thanks to the "opposition effect." The Sun-Earth-asteroid angle then will be closer to a straight line than during this month's slightly crooked arrangement. The better alignment in 2012 will increase Ceres' brightness more than the greater distance will decrease it.



Asteroid Ceres comes closer to Earth this month than at any time in the past 150 years. Look for it through binoculars as it treks slowly across northern Leo. *Astronomy: Roen Kelly*

Viewing a Titan shadow transit is the most dramatic event involving a saturnian moon, but the strange antics of Iapetus get our attention as well. One of this moon's hemispheres is snow-white; the other is charcoal-black. As Iapetus orbits Saturn, we see different proportions of these two hemispheres. This produces a striking change in brightness.

Iapetus reaches greatest eastern elongation February 23/24, when it lies nearly 10' from Saturn. Iapetus' dark hemisphere points toward Earth at this time, and the moon glows dimly at magnitude 11.9. Try tracking the moon starting February 3, when it passes 1' due north of Saturn. It appears about 2.5 times brighter than it will late in the month.

Viewing all three of February's morning planets presents a stiff challenge. Bright Jupiter will be easiest to see, although only late in the month. It will point the way to Mercury and

Mars, both of which glow much fainter.

Mercury shows up in early February, when it hugs the southeastern horizon. On February 4, it stands 8° high 30 minutes before sunrise and shines at magnitude 0.2. It grows slowly brighter during the next few weeks, although it doesn't gain any altitude for those observing from the Northern Hemisphere.

You may be able to spot **Jupiter** as early as February 17. That morning, it appears just 3° high 30 minutes before the Sun rises. You'll need clear skies and an unobstructed horizon to glimpse it. Luckily, it shines bright enough (at magnitude -1.9) to pierce the brightening twilight.

If you find Jupiter, train binoculars or a telescope on it and look for **Mars**. The Red Planet lies a single Moon's width due south of Jupiter that morning. Unfortunately, Mars glows dimly at magnitude 1.2, less than one-tenth as bright as its neighbor.



The predawn vista will be worth getting up early for February 22, when the Moon joins Jupiter and Mercury. You'll need a clear, unobstructed horizon to view this lineup. *Astronomy: Roen Kelly*

Spying it against the bright twilight will not be easy.

An attractive sight awaits early risers February 22. That morning, Jupiter, Mercury, and a waning crescent Moon line up in the southeastern sky. Jupiter appears 4° high 30 minutes before sunrise. Mercury lies 2° to its upper

right, and the slender crescent Moon stands 4° farther up.

Two mornings later, Jupiter and Mercury pass within 0.6° of each other, with Mars 4° to the pair's lower left. Although Mars remains a difficult target for the next few months, it will start to gain significant altitude late this spring. ☾

Understanding the weirdest STELLAR EXPLOSIONS

Stars swallowing planets — or each other — could explain surprising stellar outbursts. **by Laura Kinoshita**

Centuries ago, astronomers called them *stella novae*, or “new stars.” Amidst the glimmer of what was thought to be an unchanging celestial firmament, novae were quite a surprise, as well as a scientific mystery. A brilliant new star would flare to life for a brief period — days, weeks, months — and then fade into the background. People struggled to understand what they were looking at.

Eventually, astronomers figured it out. A typical or “classical” nova is the sudden brightening caused by thermonuclear explosions on the surface of a white dwarf star. Stars can also brighten dramatically in an off-the-scales stellar outburst called a supernova — the catastrophic destruction of a star. Less commonly, the collapse of a massive star can trigger a concentrated energy release called a gamma-ray burst (GRB).

This seeming simplicity is in question now. Astronomers are discovering more and more stellar outbursts that are brighter than novae, yet

not as bright as supernovae or GRBs. These intermediate outbursts radiate much more energy than ordinary periodic variable stars, which brighten moderately on a fairly regular schedule. Indeed, such a star can release enough light to temporarily outshine all others in its host galaxy. But astronomers remain uncertain what powers these outbursts.

Not to worry. Researchers have proposed some intriguing new explanations, including planets being consumed by their own stars or binary suns that collide like clumsy swing dancers. The science of stellar outbursts will never be the same — especially once the next generation of survey telescopes come online and start discovering a huge number of new examples of oddball outbursts that defy easy classification.

M85's surprise

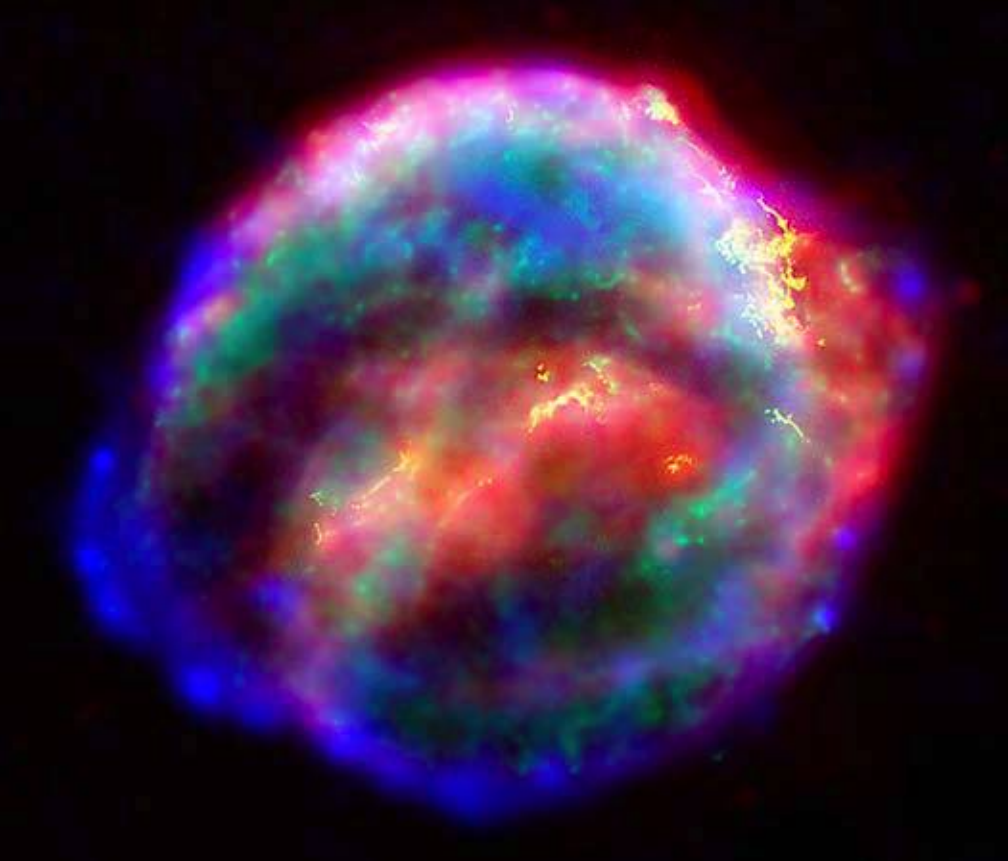
“The whole area of transient-object astronomy is on the verge of becoming very interesting again,” says Caltech Optical Observatories Director





The reddish star in the center of this Hubble Space Telescope image, called V838 Mon, brightened dramatically in January 2002. The outburst's light illuminated shells of gas around the star, as shown in this image captured February 8, 2004. Astronomers are unsure what triggered the outburst.

NASA/AURA/STScI



Visible light, infrared, and X rays combine to illuminate the supernova remnant SN 1604 in this composite image. The nova, or “new star,” mystified earthly observers when it appeared suddenly in October 1604. The legendary German astronomer Johannes Kepler observed the mysterious object for a year until it faded. NASA/ESA/R. Sankrit & W. Blair (JHU)

Shrinivas R. Kulkarni. He and his team have studied an intermediate transient star in the galaxy M85. The outburst, designated M85 OT 2006–1, flared to life in January 2006 about 7,500 light-years from the galaxy’s center. A supernova survey at California’s Lick Observatory first detected the event.

Kulkarni’s team initially observed the afterglow with telescopes at California’s Palomar Observatory. M85 OT 2006–1 didn’t fit the scientists’ suspicions that it might be a supernova. The transient was 10 times too bright to be a nova, but 10 times too faint to be a supernova.

A few weeks later, the astronomers continued their initial observations using the 10-meter Keck I telescope in Hawaii. Breaking the transient’s light into its component wavelengths, or spectrum, added to the event’s strangeness.

M85 OT 2006–1’s light became progressively redder as the outburst progressed. This indicated that the star was expanding in size, with its surface tem-

perature dropping as its energy output was spread over a larger volume of space. Kulkarni’s team suspected they might have found an entirely new type of cosmic explosion — something of unknown origin and neither a nova nor a supernova. The researchers were so impressed, they coined a new category for M85 OT 2006–1: luminous red novae (LRNe).

Exciting oddballs

As word of M85 OT 2006–1 spread, it became clear that Kulkarni’s red nova wasn’t the first of its kind astronomers had seen. In 1988, telescopes had caught a glimpse of a star that flared to brilliance in the central bulge of the Andromeda Galaxy (M31). This star’s light also had a reddish cast. Astronomers designated it M31-RV, meaning “red variable in M31.”

When a nondescript star suddenly brightens by many orders of magnitude, astronomers may suspect it is a nova. Novae involve a particular type of star, the compact remnant of an aged Sun-like star called a white dwarf. A white dwarf is what stars like our Sun will evolve into after exhausting their hydrogen fuel.

Because stars frequently come in pairs (binaries), many white dwarfs draw gas from a nearby companion star. When the dwarf’s gravity compresses hydrogen in the stolen material to a critical density, it ignites with nuclear fusion and causes the star to brighten dramatically. Classical novae can flare up quickly or gradually, but the underlying process is the same: nuclear fusion.

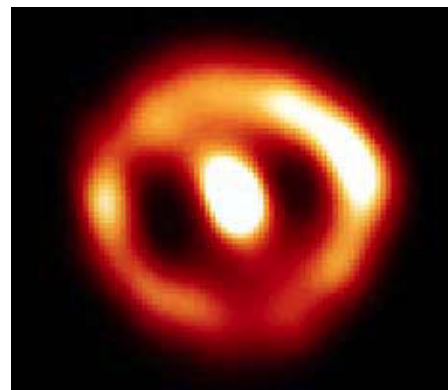
M31-RV was clearly not a nova. For one thing, it was too bright. There are theoretical limits on how much energy a nova can crank out, and M31-RV was too luminous. However, it was not bright enough to be a supernova.

An important clue came from the transient’s spectrum. Observations of M31-RV were not particularly extensive, but observers collected enough data to conclude that the outburst’s light was cool and red. Astronomers weren’t quite sure what to make of M31-RV.

Echo star

Nature provided another glimpse of a luminous red transient in January 2002. Amateur astronomer Nicholas J. Brown of Quinns Rocks, Western Australia, discovered what he thought was a nova in the constellation Monoceros and then faded. Astronomers designated the event V838 Mon, or the 838th variable star observed in Monoceros.

But the star brightened again a month later, faded, and then surged yet again the following month. At the height of its flare-up, V838 Mon shone 600,000 times



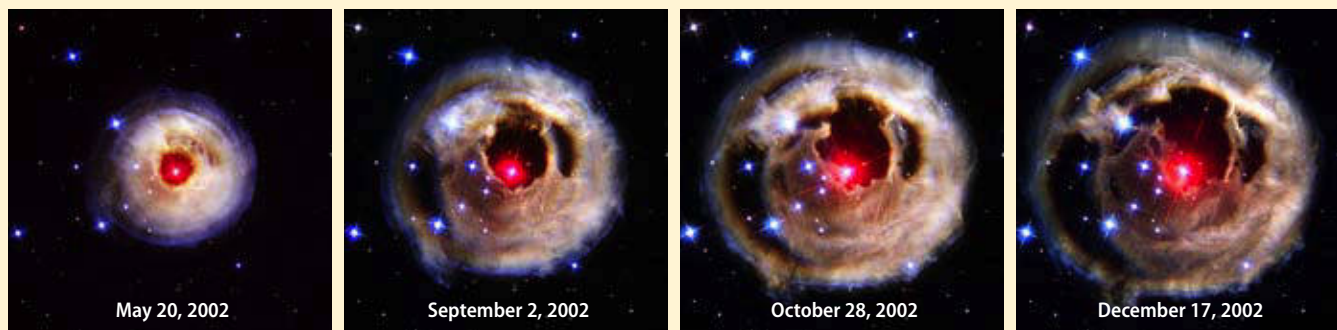
A gas shell balloons outward from a brilliant stellar outburst, Nova Cygni 1992. It was a typical nova, in which hydrogen detonated after being dumped on the star’s surface by a nearby companion. The Hubble Space Telescope captured this image May 31, 1993, just over 15 months after the explosion. Francesco Parasci/ESA/STScI/NASA

Laura Kinoshita is a NASA/Jet Propulsion Laboratory Solar System Ambassador and writes about astronomy from her home in Hawaii.

Light echoes from V838 Monocerotis

In these Hubble Space Telescope images, a flashbulb-like pulse of light from the central star, V838 Monocerotis, illuminates concentric gas shells. Reflections from different shells arrived at Earth from May

to December 2002. The images create the illusion of debris expanding outward from the star. In reality, the same pulse of light illuminates the cloud at increasing distances from the center.



NASA/ESA/Howard Bond (STScI)

brighter than the Sun and swelled to 500 times its former diameter. If the star were in our solar system, it would have ballooned nearly out to Saturn's orbit.

The Hubble Space Telescope provided a detailed look at V838 Mon over a period of years. Again, unlike a classical nova, the outburst's light has grown cooler and redder. "In fact, at the present time, it's one of the coolest known stars," says Howard E. Bond of the Space Telescope Science Institute in Baltimore. Bond led the Hubble team observing V838 Mon. "A normal nova is the opposite. As the ejected layers expand, they become thin, and you can see down into the underlying hot source. A classical nova becomes bluer."

V838 Mon wasn't just weird — it was beautiful. Since 2002, Hubble has imaged spectacular "light echoes" bouncing off

dust and gas surrounding the star. The sudden pulse of light from V838 Mon's outburst illuminated its surroundings like a flashbulb. The pulse bounced off concentric gas shells around the star, creating multiple light echoes that reached Earth at different times. The result was a time-lapse effect in which the gas and dust appeared to be expanding around the star. It was the most spectacular display of light echoes ever seen.

The red source

While the public marveled at the colorful portraits of V838 Mon, astronomers struggled to understand its unusual three-step brightening pattern. Where did the energy come from?

V838 Mon and similar intermediate stellar outbursts seem so novel that not all scientists go along with Kulkarni's new LRNe category. "It's clear that these are new types of stars, but we cannot call them novae because the mechanism that causes this outburst is not like that of a nova," says astrophysicist Alon Retter, formerly at Pennsylvania State University and now at Israel Aerospace Industries, Ltd.

Nuclear fusion powers novae, but not V838 Mon. Whatever the source of the energy, it must be pretty substantial. "You have a formerly inconspicuous star that, within a matter of weeks, expands to become the size of Saturn's orbit," Bond says. "Something deposited a lot of energy in whatever the progenitor was."

Right after V838 Mon's flare-up, Retter and several colleagues proposed a theoretical model called planet capture.

The essence of the idea is that a planet (or planets) falling into V838 Mon provided the energy for the star's dramatic three-stage brightening.

In the model, V838 Mon expands until it engulfs a planet orbiting the star. Retter and his colleagues estimate that a gas planet roughly the mass of Jupiter could supply enough energy to account for V838 Mon's outbursts.

The planet's position in orbit represents stored "gravitational energy," Retter says. Friction with the star's expanding outer atmosphere causes the planet to sink to a lower orbit, shedding a portion of its gravitational energy as heat. The energy injection brightens the star.

The inspiraling planet eventually reaches a depth where the stellar atmosphere's density matches its own. At that point, which Retter calls the "critical density," the planet can sink no farther. It essentially surfs on the denser mass below, like a submarine that has trimmed its buoyancy to cruise in midwater.

To explain V838 Mon's three-stage brightening, the star would have to consume three planets consecutively. As an alternative, Retter and his colleagues also sketched a scenario in which a single planet experiences a three-step descent.

After the planet's initial engulfment, the star continues to expand. This spreads the same volume of stellar material more thinly. As a result, the planet's surroundings grow less dense and the critical density point sinks lower. This allows the planet to resume its downward spiral, releasing energy and fueling another peak in the star's output.

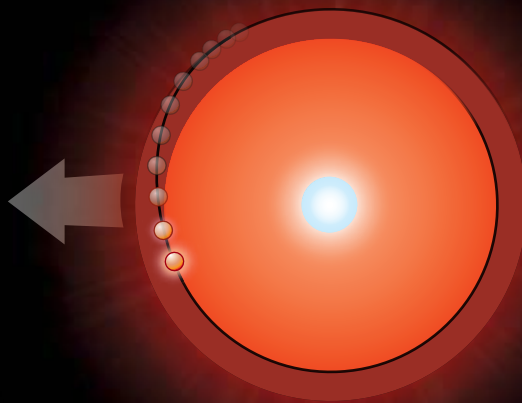


Supernova 1994D exploded in the outskirts of galaxy NGC 4526 in the Virgo cluster. SN 1994D was a type Ia supernova, triggered by the collapse and catastrophic destruction of a white dwarf star. NASA/ESA/High-Z Supernova Search Team

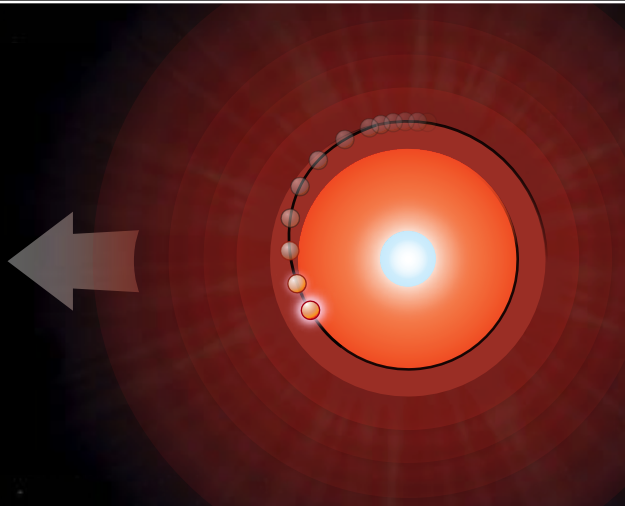
Can planets feed stellar outbursts?

The star V838 Monocerotis brightened and dimmed three times in 2002 in as many months. The star's bizarre behavior has fueled the imaginations of theorists like astrophysicist Alon Retter. He and his colleagues have proposed an explanation called planet capture. V838 Mon's outer atmosphere consumes a planet, releasing energy that swells and brightens the star. The sequence below shows a three-stage engulfment of the same planet. In an alternative version of the capture model, the expanding star consumes three different planets. *Astronomy: Roen Kelly*

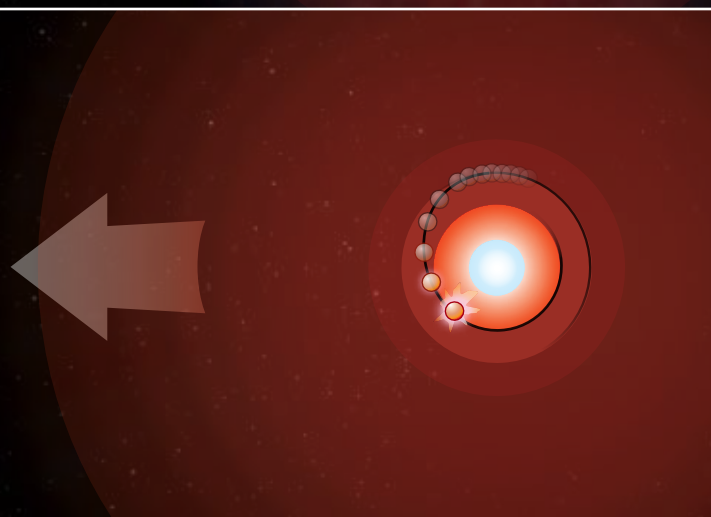
As the star engulfs the planet, friction forces it to a lower orbit. To reach its new orbit, it sheds gravitational energy in the form of heat, which brightens the star. The planet spirals to a lower orbit until the surrounding stellar atmosphere reaches a "critical density" and slows down. The planet can sink no farther, so it continues to orbit at this depth.



With continued expansion, the critical-density point lies deeper in the star's atmosphere. The planet begins to spiral downward again, releasing energy and brightening the star. The planet stops sinking when it hits the critical-density "wall."



After a final round of stellar expansion, the planet spirals deeper, releasing more energy to brighten the star. At this point, the planet is completely consumed.



The planet eventually reaches the critical density again that prevents it from descending any deeper. After a third round of expansion and sinking, the planet is completely consumed near the hot core of the star.

Merger in Monoceros

Noam Soker of the Technion-Israel Institute of Technology in Haifa and colleague Romuald Tylenda of the Copernicus Astronomical Center in Torun, Poland, also developed a planet-capture model to explain V838 Mon's brightening, but rejected it. Their alternative to planet capture is the "mergeburst" model.

Soker and Tylenda say the merger of two stars in a binary system could provide enough energy at the right times to explain V838 Mon's behavior. According to their calculations, V838 Mon's stellar system consisted of a large, aging primary star packing about 8 times the Sun's mass. Its smaller companion or "secondary" weighed in at 0.3 solar mass.

In a binary system, two stars orbit a common center of gravity. But at V838 Mon, Soker and Tylenda speculate, the orbits grew too close for comfort. Computer models indicate that as a binary system merges, the stars make about three grazing passes before becoming a single mass. The merger model also explains the three peaks seen in V838 Mon's early outburst. With each pass, Soker says, a chunk of mass could tear away from one star and crash into the other, releasing energy.

After several close calls, tidal forces tear the secondary star apart. It ends up as a shell of hot gas encircling the primary. The added mass and energy swells the star out to 1,000 times the Sun's radius. But it gradually cools and contracts, emitting most of its energy as visible light, and later in the infrared.

Soker says his merger theory is testable. As the rotating merged star cools and contracts, it should "spin up" faster and faster, like a twirling figure skater drawing her arms inward. It would be difficult to detect the rotation itself. Instead, Soker says, they might be able to observe a secondary effect of rotation, which is the creation of a field around the star. Given a strong enough magnetic field, the merged binary system might start emitting X rays.

Soker and Tylenda teamed up with Joel Kastner, a colleague at the Rochester Institute of Technology in New York, to check V838 Mon for signs of a magnetic field. Using the European XMM-Newton satellite in March 2008, they looked for X-ray emissions and found none. “This says the star isn’t showing magnetic activity — yet,” Soker says.

Drinking from a firehose

Planet capture and mergebursts are just two possible explanations for V838 Mon’s mysterious outburst. Some astrophysicists think atypical, nova-like nuclear reactions could still explain the event. At the moment, astronomers have only a small number of events to mull over. The limited observational data on a limited number of intermediate stellar outbursts creates fertile soil for speculation.

What astronomers need are more examples of transients that fall between novae and supernovae, so they can refine their theories. In the near future, they will probably get their wish. New survey

“The more
we observe, the more
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telescopes will come online in the next decade that could detect more transient events in a single night than astronomers formerly accomplished in a year.

Among the more well-known projects is the Large Synoptic Survey Telescope (LSST), scheduled to begin operations in 2014. Another new wide-field survey instrument, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS), should be operational in 2011.

Frequent high-resolution mapping of the entire night sky is on the horizon. “I wouldn’t be surprised if in 10 years we are able to get, more or less, a picture of a large fraction of the sky, at high resolu-



From atop Chile’s Cerro Pachon, the Large Synoptic Survey Telescope (LSST) will image the entire sky accessible to the instrument every 3 days. The observatory, shown above in an artist’s concept, will detect many new transient events and advance scientists’ understanding of their causes. Michael Mullen Design (LSST Corporation)

tion and high sensitivity, every second,” Kulkarni says. “It sounds outlandish now, but it’s as outlandish as the idea 30 years ago that everybody would have computers in their homes.”

Just the output of one instrument like the LSST would overwhelm astronomers with new detections of transient events. “It will be like drinking from a firehose,” Bond says. “We’re going to have to be very selective in what we follow up on.”

Attracting attention

Enter astronomer Joshua Bloom of the University of California at Berkeley, who studies one of nature’s most powerful transients — gamma-ray bursts, or GRBs. He’s also a leader in the movement to marshal robotic telescopes to observe fleeting transients like GRBs. Bloom is developing software that will allow computers to make intelligent decisions about which objects they should follow up on.

Bloom hopes astronomers will discover new types of outbursts that don’t fit any known physical mechanism or are on the extreme side of the astrophysical processes at work. “It’s the objects on the periphery of any class that wind up teaching you a lot about the general population itself,” he says.

Soker suspects astronomers will discover multiple classes of stellar eruptions with causes that are neither novae nor supernovae. He compares the state of knowledge about objects like V838 Mon to that of GRBs decades ago. “We discov-



A mosaic of light-sensitive elements, or charged-coupled devices (CCDs), form the core of the Large Synoptic Survey Telescope (LSST) camera. Above, LSST Public Outreach Specialist Suzanne Jacoby holds a mock-up of the scope’s imaging element, including an image of the Moon to indicate what a large portion of the sky the camera images simultaneously. LSST Corporation

ered them 40 years ago, and even 15 years ago we didn’t know what they were,” Soker says. “Now we have solved a large part of the problem.”

New detections from survey scopes would naturally attract astronomers’ attention to oddball intermediate stellar outbursts that, right now, remain rare and small in number. “If we discover more of the transient events, priority will be given to observe them,” Soker says.

Astronomers will no doubt welcome all the new data. Observations are the key to advancing our knowledge of the universe, Bond emphasizes. After all, that’s how we found out about oddball transients like V838 Mon and M85 OT 2006–1. “Nobody would have predicted this theoretically,” Bond says. “It takes observations. The more we observe, the more we discover things that nobody had even thought of.” ☛



Listen to astronomer Howard Bond talk about V838 Mon’s spectacular light echoes at www.Astronomy.com/toc.

What can we “see” with radio waves?

Q: What do radio telescopes observe, and how does it relate to the visible sky? — Michael McNamara, Bakersfield, California

A: Radio and optical astronomy reveal different, although complementary, information about the universe. Just like optical telescopes, radio telescopes measure energy radiating from a particular sky location. The difference is that the energy arrives in the form of radio waves, not light.

Radio telescopes allow us to study objects that emit scant visible light, like organic molecules in dusty interstellar clouds, and to detect invisible emissions like cosmic rays near a black hole.

Among the brightest objects in the radio sky are quasars and supernova remnants, but they shine dimly in vis-

ible wavelengths. On the other hand, many of the brightest stars visible in the night sky remain virtually undetectable to radio telescopes. Still, some objects are bright in both wavelength ranges, like the Orion Nebula (M42) and the Rosette Nebula in Monoceros.

The naked eye cannot perceive radio waves, of course. But because the human visual system is so good at seeing patterns and spatial relationships, radio astronomers regularly transform their data into images similar to the way physicians convert X-ray scans into anatomical views. — **Felix J. Lockman**, National Radio Astronomy Observatory, Green Bank, West Virginia



Extended lobes of radio emission fan out from NGC 1316 (center), a giant elliptical galaxy in the process of devouring its small neighbor to the north. Each radio lobe spans 600,000 light-years and results from high-energy particles beamed in opposite directions from NGC 1316's central black hole. Astronomers merged the radio data with an optical image from the Digitized Sky Survey to create this composite. Ed Fomalont (NRAO)/Ron Ekers (ATNF)/Wil van Breugel & Kate Ebner (UC-Berkeley)/J. M. Uson

GALACTIC CENSUS

Q: How many stars does our galaxy contain? — Andy Mance, Toledo, Ohio

A: Most astronomers roughly estimate the Milky Way contains at least 100 billion stars, but the actual number may be as high as 400 billion.

The greatest obstacle to determining the number of stars in the Milky Way is that the galaxy's most common stars, M dwarfs, are dim. Surveys detect M dwarfs only if they are relatively nearby.

Estimating the galaxy's stellar population involves three steps. Astronomers measure the ratio of bright stars near the Sun to faint stars. They also count the brightest stars throughout the galaxy to estimate the number of stars in different galactic structures — the bar, disk, spiral arms, and halo. And finally, astronomers must make assumptions about how the ratio of bright stars to faint stars varies among different parts of the galaxy.

This process involves many uncertainties. Some estimates indicate the galaxy has as many as 400 billion stars. This may represent a more exact accounting effort, but it still lies within a factor of 10 of the cruder estimate of 100 billion stars. — **Robert Benjamin**, University of Wisconsin-Whitewater

COSMIC SCAFFOLD

Q: Does dark matter clump together like ordinary matter? — John Lowe, Calgary, Alberta

A: Dark matter does clump under its own gravity. Although dark matter emits no light, we can infer its presence because it acts under the influence of gravity. Large amounts of dark matter collect in galaxy clusters. Astronomers have also created large-scale maps that clearly indicate dark matter is not distributed uniformly in the universe.

In the past, some astronomers have claimed to find concentrations of dark matter with no associated visible mate-



How many planets lie beyond Pluto?
Find out at www.Astronomy.com/toc.

KEY WORDS

Bow shock

The point at which interstellar gas first encounters the heliosphere.

Dark matter

Particles that emit no light but have a gravitational influence on each other and on normal matter.

Heliosphere

A bubble blown in interstellar gas by particles flowing from the Sun.

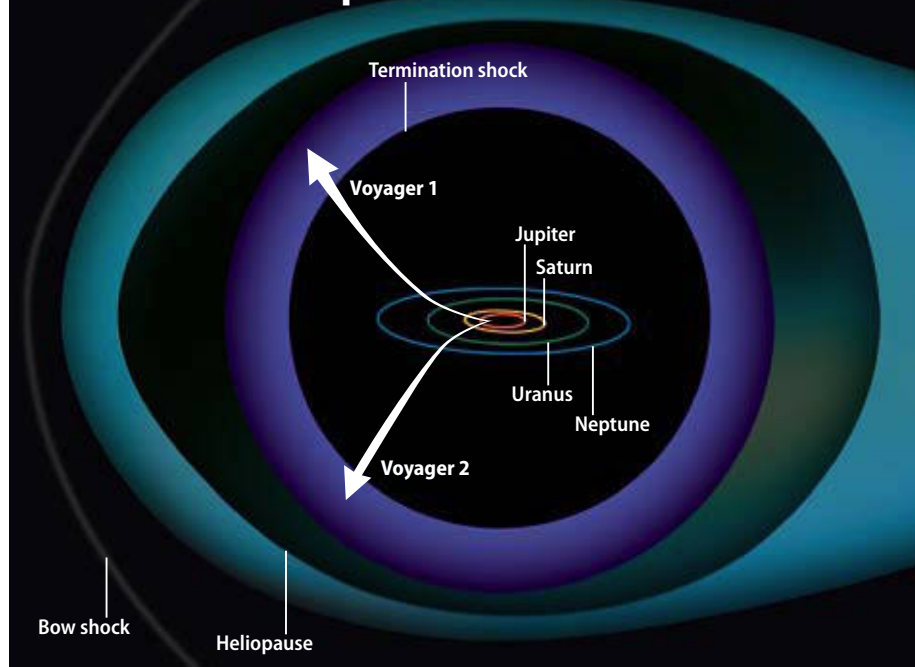
Heliopause

The point at which inward pressure from interstellar gas and the out-flowing solar wind strike a balance.

Termination shock

The point where the solar wind abruptly decelerates.

Inside the heliosphere



After visiting the outer planets, the Voyager spacecraft crossed the heliosphere's termination shock — the zone where the fast-moving solar wind abruptly slows — at different distances. This suggests that the northern portion of the heliopause extends farther from the Sun than the southern side. The distortion may trace to the effect of interstellar magnetic fields. *Astronomy: Roen Kelly*

rial. On closer examination, these claims have turned out to be inaccurate. Dark matter resides only in places where visible matter also exists.

There's a good reason for this association. Concentrations of dark matter attract hydrogen gas, which then cools and forms stars. Think of dark matter as the scaffolding around which visible matter in the universe clumps. — **Richard Ellis**, California Institute of Technology, Pasadena

SOLAR BUBBLE

Q: What are the heliosphere, the termination shock, and the heliopause? — **Anne Rush**, Rockford, Illinois

A: They are structures within the transition zone between the Sun's "solar wind" and the larger interstellar environment.

The heliosphere is a region of space containing hot ionized gases and magnetic fields from the Sun. The Sun's outflow of charged particles (the solar wind) carves this cavity from interstellar gas.

The solar wind flows from the Sun at a speed of about 900,000 mph (1.44 million km/h). The heliopause is the outermost boundary between the solar wind and the interstellar gas. As the Sun moves through the gas, the heliopause becomes warped into a bullet shape.

The inward pressure from interstellar gas stalls the solar wind's expansion at the heliopause. Before reaching the heliopause, the solar wind abruptly slows to about 224,000 mph (360,000 km/h). This sudden velocity change occurs at the termination shock.

In August 2007, Voyager 2 crossed the termination shock at a distance of about 8 billion miles (13 billion kilometers) from the Sun. That's 10 percent closer than Voyager 1's 2004 crossing. This suggests that the heliopause is slightly squashed, a distortion the interstellar magnetic field may have caused.

— **Donald A. Gurnett**, University of Iowa, Iowa City

UNWRITTEN IN STONE

Q: Why are there no stone carvings or evidence of writing at Stonehenge? Didn't the builders have some written language or symbols? — **Richard Olshausen**, Laguna Beach, California

A: The Neolithic farmers who built Stonehenge and other similar structures had no writing. But they may well have used other kinds of symbols. The passage tomb of Newgrange in

Ireland, which dates from about the same time as Stonehenge, is decorated with geometrical patterns, including a complex trio of overlapping spirals discovered at the back of the tomb.

It's not clear what these patterns represent. One guess is that they symbolize the Sun. Newgrange, like Stonehenge, has an unambiguous solar orientation. Sunlight reaches the back of the chamber only on the winter solstice.

Stonehenge lacks such pictograms, but one might say that the stones themselves have symbolic value: They may have signified life and death, past and future, ancestors and gods.

Other Neolithic peoples, such as the Vinča culture of southeastern Europe, seem to have had at least a rudimentary system of writing. But this innovation does not seem to have reached the continent's northwestern frontier. — **Dan Falk**, science writer, Toronto

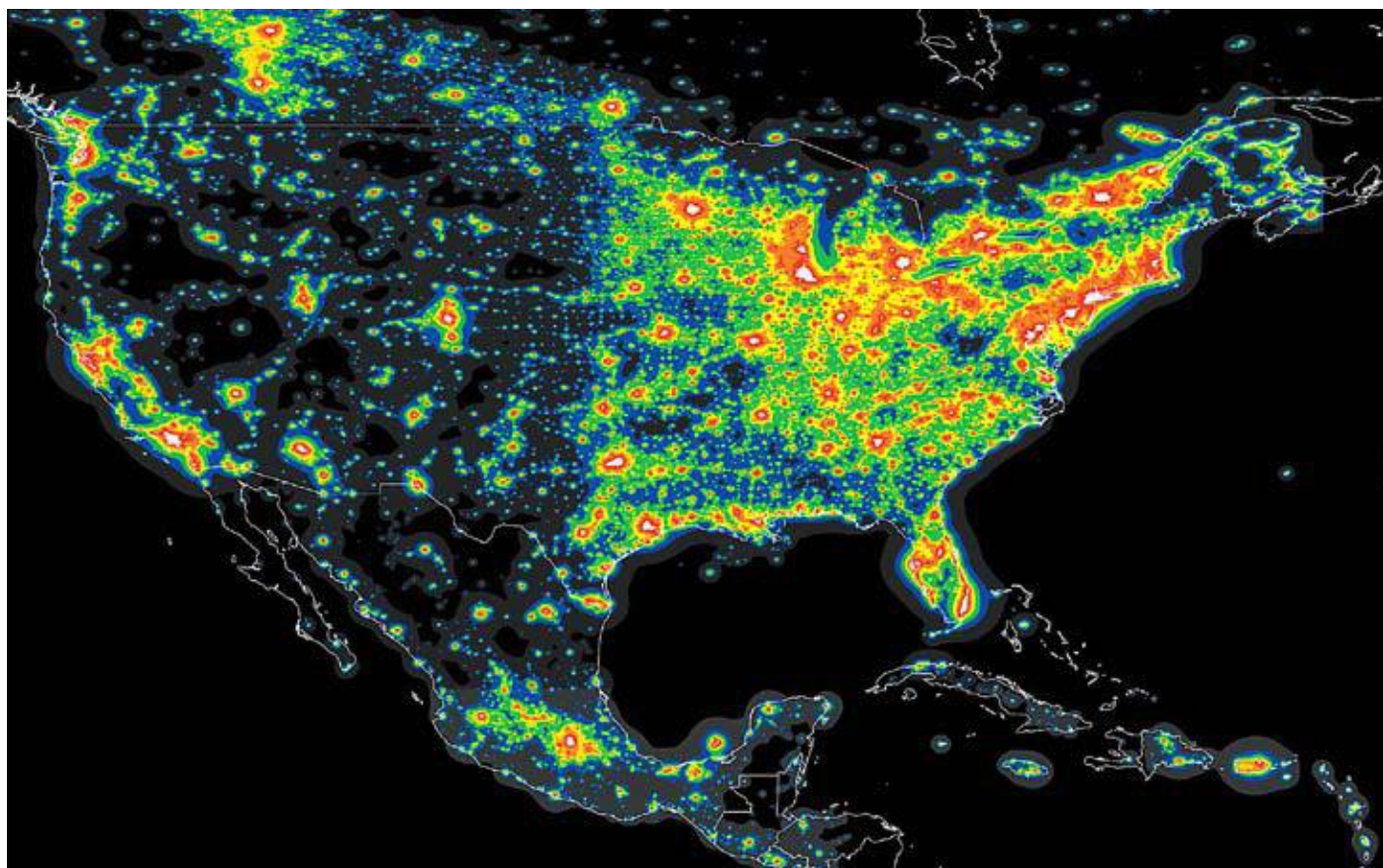
Send your questions via e-mail to: askastro@astronomy.com; or write to **Ask Astro, P.O. Box 1612, Waukesha, WI, 53187**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.



Army of darkness

Can we win the war against light pollution?

The night sky is getting brighter. Here's how we can reverse the trend. **by Michael E. Bakich**



Istituto di Scienza e Tecnologia Dell'Inquinamento Luminoso

Observers, astrophotographers, and nature-lovers all have a common enemy: light pollution. This insidious problem, caused by excess nighttime lighting, is growing worldwide. Satellite images show few regions of our planet's nightside are truly dark. It's possible, in fact, that the Moon is the only object young people in large cities will ever see. Indeed, the dark night sky is an endangered natural resource.

Nobody denies that some outdoor lighting is necessary for people's safety

Michael E. Bakich is a senior editor of *Astronomy*.

and security. Other lighting, such as that used for advertising, may not be necessary, but it's a consequence of living in our world today. If those lights are designed and maintained correctly, they can be a benefit without taking away from the night sky's beauty.

Defining the problem

Outdoor light pollution manifests itself in three ways: light trespass, glare, and clutter. Light trespass occurs when unwanted external light enters your property. It can ruin an imaging session or cause sleep deprivation if bright light enters through a bedroom window.

This color-coded map of light pollution across the United States shows the darkest areas as black. These areas generally are remote. Gray and mauve regions are ideal hunting grounds for pristine skies. Often, these areas are rural and are not accessible by road. Green sections have acceptable dark-sky conditions. If you don't have access to any of the black areas (as will be the case in many of the northeastern states), go for the green.

Glare results from high contrast between lit and unlit areas. Although it affects amateur astronomers, it's most often a problem for drivers. Bright streetlights, advertising signs, and poorly placed lights used by businesses are the primary causes of glare.



Bad lighting in El Paso, Texas — and many other cities — has multiplied in recent years. If not for the mountains in the background, these lights might have gone on farther. Michael E. Bakich

Clutter refers to badly designed or excessive light groups that generate confusion or cause safety issues. This generally affects automobile drivers.

The light stops here

The best outdoor lighting falls under the classification “full-cutoff.” Full-cutoff fixtures do not allow light to escape above 90°, which marks the edge of the lamp’s shade. Such fixtures distribute light in a directed pattern and provide equivalent ground lighting with less power. The first full-cutoff light fixture was General Electric’s M100, introduced in 1959.

Many states mandate full-cutoff lights for building or highway construction. Today’s full-cutoff fixtures generally employ high-pressure sodium lamps. Introduced in 1970, they are the dominant streetlights in the United States. The main characteristic is their orange-yellow



Earth at night gets less dark every year. As this image shows, the worst offenders are the United States and Europe. Data courtesy Marc Imhoff of NASA GSFC and Christopher Elvidge of NOAA NGDC. Image by Craig Mayhew and Robert Simmon, NASA GSFC.

glow. They use far less energy than mercury-vapor or metal-halide lamps.

Government action?

In August 2008, the International Dark-Sky Association (IDA) worked with Congress on a bipartisan letter in support of light pollution research and education. Signed by 11 U.S. Congressional repre-

sentatives, it asked the U.S. Environmental Protection Agency (EPA) to take four steps against light pollution:

- 1) Codify a formal definition for “light pollution” that captures the detrimental effects that result from unchecked nighttime illumination.
- 2) Incorporate consideration of the environmental, safety, and health effects



With all the bad lighting in this photograph, it’s tough to pick out the one light (arrow) that conforms to the full-cutoff standard. Michael E. Bakich

Confronting light pollution: National Dark Sky Week

Each year, the International Dark-Sky Association (IDA) chooses one week during which they hope everyone in the United States helps to temporarily reduce light pollution. It’s called **National Dark-Sky Week** (NDSW). The IDA encourages us all to turn off unnecessary lights so we can realize the wonder that our universe holds. If everyone participates, NDSW will inspire us to use better lighting systems. NDSW was founded not only to reduce light pollution, but also to help people connect with the night sky.

NDSW usually occurs in April during the week of New Moon. This year, New Moon occurs April 25. So, across the United States,

amateur astronomers and concerned citizens will participate in NDSW each night between April 20 and April 26 from 10 P.M. to 12 A.M. EDT.

Besides raising awareness of the problem, NDSW’s goals are to reduce light pollution temporarily, allowing us to see the night sky in greater detail; encourage people to use better light fixtures; and give everyone a greater appreciation for astronomy, thus recruiting others to help reclaim our dark skies lost because of poor lighting. If you want to get involved with NDSW, visit star parties and observatories that are hosting local events. — M. E. B.



Forget about astronomy for a moment. These streetlights produce so much glare that safety is the issue for drivers and pedestrians. Michael E. Bakich

of current levels of light pollution into EPA research programs.

3) Expand the discussion of well-designed (and thus energy-efficient) outdoor lighting in [the federal efficiency program] Energy Star publications and standards.

4) Support education about light pollution in the agency's education, outreach, and grant programs.

"Encouraging the EPA to address light pollution is a great first step at federal protection of our night skies," says Christian K. Monrad, president of the IDA Board of Directors. "We [IDA] estimate that there are approximately 2,500 outdoor lighting codes in the U.S. alone; some of them very well-written and others that are not. Having federal research and recognition of light pollution would

assist states and municipalities in having a solid baseline for future codes and revisions to current ones."

Moving to protect dark skies, Energy Star included specifications for full shielding of solid-state streetlights in its proposed criteria for 2009. If passed, the requirements will impact the design of all future LED (light-emitting diode) streetlights. These criteria are the result of input gathered at a series of Department of Energy (DOE) sponsored workshops.

Energy Star is America's most widely recognized energy efficiency program. It began in 1992 as a cooperative effort between the DOE and the EPA. Energy Star's primary goals are to save money and reduce environmental impact through energy-efficient products and practices. Visit the Energy Star web site at

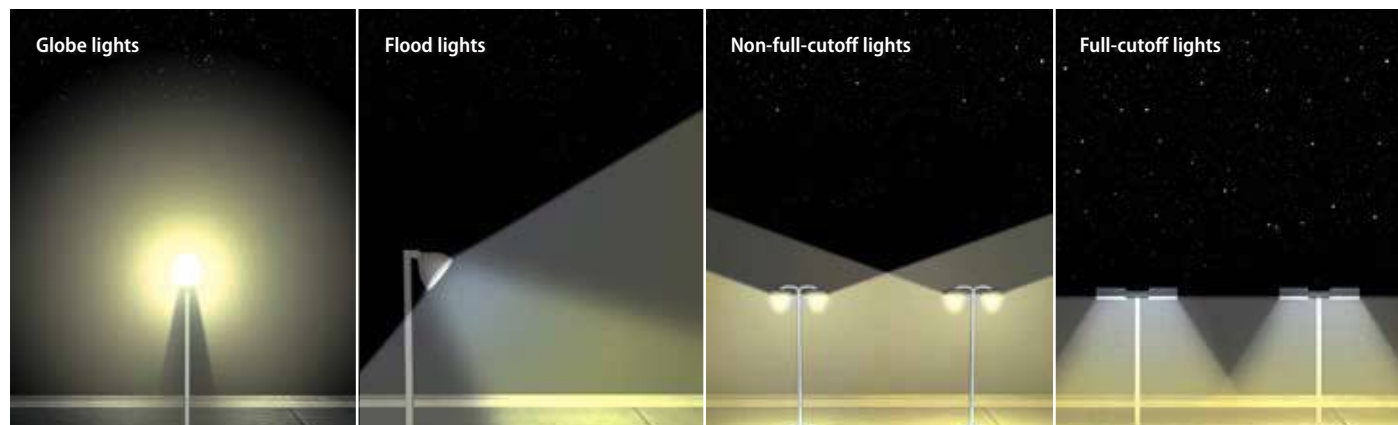
<http://www.energystar.gov> for more information about Energy Star's goals.

What can you do?

I talked to a leading vendor of approved light fixtures, Anthony Arrigo, president of Starry Night Lights. He's come up with 10 ways you can help in the fight against light pollution. They're listed here with only slight modifications:

1) Light only what needs lighting. This sounds simple, but it typically gets overlooked. Ask yourself, "Does this even require lighting?"

2) Light only when you need it to be lit. OK, so you've determined that it really requires light. Does it need to be lit at all times? If you go out to your shed only once a week, does it really need to be lit dusk to dawn every night?



Progressively better outdoor lights (left to right) reduce both glare and sky glow. The best lights employ full-cutoff shades, which direct light below the horizontal, sending the least amount of light into the sky. Astronomy: Roen Kelly

Fleeing light pollution: Arizona Sky Village

Many folks who seek a remedy for light pollution have taken up residence in premier observing locations. The country's most ambitious astronomical development is Arizona Sky Village (ASV).

Located in the foothills of the Chiricahua Mountains, ASV sits at the mouth of Cave Creek Canyon in Portal, Arizona. Four-acre lots of deed-restricted property and Interval Ownership Haciendas (time shares) occupy this expanse of high desert. Several dozen homes already populate the development.

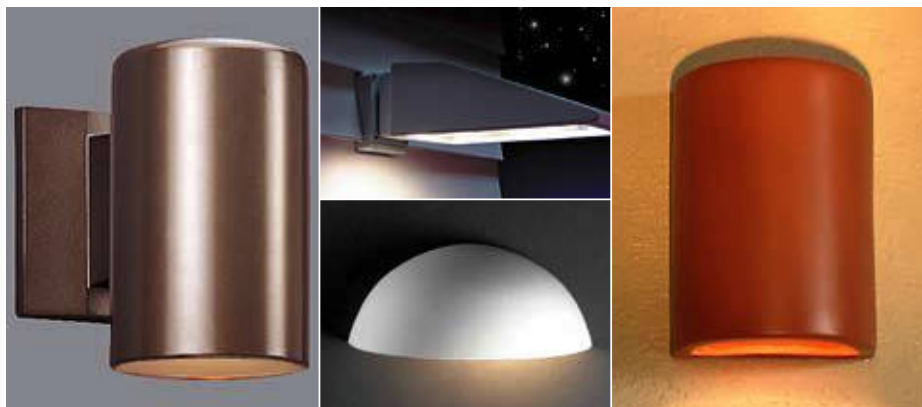
Arizona Sky Village is the vision of its first residents, Gene Turner and Jack Newton. Turner combines a lifelong fascination with astronomy with a career in real estate development to manage the project's nuts and bolts. Newton, a leading astroimager for decades, is a household name among amateur astronomers. He's producing his best images ever from his observatory on the ASV site and also has discovered several supernovae.

ASV's sky is only a couple tenths of a magnitude brighter than the most remote locations on Earth. Southeastern Arizona enjoys a dry, yet moderate climate characterized by insignificant snow and tolerable summer heat. Its latitude is southerly enough to elude cold fronts and far enough west to remain dry.

Developments such as Arizona Sky Village represent the future of dark-sky astronomy. Filling desirable locations with amateur astronomers can only help to keep light pollution at bay. — *M. E. B.*



This light fixture, installed when a restaurant opened, is an example of extreme light pollution because of the amount of light it emits horizontally. People with no interest in astronomy complained about it from the first night it went into operation. Michael E. Bakich



This selection of IDA-approved lighting is part of the line offered by Starry Night Lights. As these examples show, full-cutoff lights don't have to be ugly to be effective. Images courtesy starrynightlights.com

3) Use only as much light as is required. Don't always install the highest available wattage. If you're not performing surgery on your patio, there's no need for operating room illumination levels.

4) Use only full-cutoff light fixtures. Full-cutoff fixtures shine light onto the ground and prevent light from crossing property lines or up into the night sky.

5) Shield existing fixtures. If you're not quite ready to install new, full-cutoff fixtures, light shades are available for many fixtures. Shades will convert the fixtures into night-sky friendly fixtures for a minimal cost.

6) Install motion sensors. Such devices will turn your lights on automatically

whenever there is activity outside your home or business. Taking this step typically reduces your use of electricity for lighting by more than 90 percent. Such a saving easily pays for the cost of the sensor and its installation.

7) Install reflectors. Many times, you can use reflectors to outline a driveway instead of a string of lights. Reflectors are cheaper to purchase, cost nothing to run, and are unaffected by power outages.

8) Get used to the dark. Our eyes are quite good at night. If you take the trash out at night, do you need to turn your outdoor lights on? Chances are good that you'll be able to find the trash can and make your way to the curb.

9) Educate those around you about light pollution. This includes your family, friends, neighbors, and elected officials. With just a little bit of thought and effort, light pollution is one type of environmental problem that can be cleaned up without any side effects.

10) Show your support for current efforts. Help promote groups such as the International Dark-Sky Association and manufacturers who produce approved fixtures. If you blog, write about light pollution. Don't just gripe! Mention success stories whenever you can.

Taking a proactive approach to light pollution ensures that future nights will be safe, healthy, and dark. ☾



Deep-sky astronomy

All about M81 and M82

These galactic gems offer a dazzling sight and high-level astrophysics to boot. **by Raymond Shubinski**

High in the north lies Bode's Galaxy (M81), one of the sky's brightest galaxies. Once you spot it, head 0.6° north, and you might think you're seeing a galaxy explode. Not exactly. What you've found is the Cigar Galaxy (M82), the classic example of a starburst galaxy.

Together, M81 and M82 represent one of the heavens' finest extragalactic close-pairs. These two galaxies have provided professional and amateur astronomers with many challenges and puzzles. Each is worthy of its own story, but they're inextricably linked by discovery, observation, and science.

Celestial setting

Ursa Major the Great Bear is the sky's third largest constellation. Within it, the seven-starred asterism of the Big Dipper is one of the first sky figures children in the Northern Hemisphere learn to recognize. You'll see many treasures here with the slightest optical aid. One is the optical double star Mizar (Zeta [ζ] Ursae Majoris) and Alcor (80 Ursae Majoris).

The constellation's mythology is ancient, and many cultures tell stories about a bear in this part of the sky. Because the constellation is so large, finding the ursine figure can be a bit tricky. The body is the four bright stars of the Dipper's bowl. The back legs extend out from Phocda (Gamma [γ] UMa), while the front legs drop southward from 3rd-magnitude Theta (θ) UMa. The head of the bear is a faint trio of stars with Muscida (Omicron [ο] UMa) marking the nose. Looking just north of the bear's ears, steadily held binoculars will let you resolve two faint patches of light — M81 and M82.

Because of their high northern declinations — nearly 70° — M81 and M82 are circumpolar objects (they never disappear below the horizon) for amateur astronomers who observe from



The Cigar Galaxy (M82) makes a great target for astroimagers. Classified as a starburst galaxy, M82 has an extremely high rate of star formation and supernova activity. NASA/ESA/The Hubble Heritage Team (STScI/AURA)

locations north of latitude 21° north. An optimal time to view these galaxies would be in mid-April a few hours after sunset. Their sky positions (celestial coordinates) lie opposite the Sun in mid-February. Around that time they attain their highest position around midnight.

At magnitude 6.9, M81 is the more luminous of the pair and one of the sky's brightest galaxies. It presents itself as a massive grand design spiral; that is, one with clearly defined and well-organized arms. Fainter M82, once called an irregular galaxy, clearly shows the disrupted features of a close gravitational encounter with M81. Such interaction causes star formation to run amok, so astronomers classify M82 as a starburst galaxy.

Historical setting

On a cold New Year's Eve in 1774, German astronomer and celestial cartographer Johann Elert Bode (1747–1826) was scanning the sky near the head of Ursa Major the Great Bear. Like



This M82 composite combines images from Hubble, Chandra, and Spitzer. X-ray data recorded by Chandra appears here in blue; infrared light recorded by Spitzer appears in red; Hubble's observations of hydrogen emission appear in orange; and the bluest visible light appears as yellow-green. Chandra data: NASA/CXC/JHU/D. Strickland; Spitzer data: NASA/JPL-Caltech/C. Engelbracht (University of Arizona); Hubble data: NASA/ESA/The Hubble Heritage Team (STScI/AURA)



Bode's Galaxy (M81) has well-developed spiral arms containing reddish star-forming regions. It shines as one of the sky's brightest galaxies at magnitude 6.9. NASA/ESA/The Hubble Heritage Team (STScI/AURA)

many mid-to-late 18th-century astronomers, he wanted to make star catalogs and discover comets. Throughout the 18th century, many improvements in the refracting telescope had made this work practical.

On that night, his eye was drawn to two fuzzy objects. He described the brighter as “a nebulous patch, more or less round, with a dense nucleus in the middle.” The other he called “a nebulous patch, vary pale; elongated.”

French astronomer Pierre Francois André Méchain (1744–1804) independently discovered both galaxies in August 1779. He reported them to his friend, comet-hunter Charles Messier (1730–1817), who added them to his now-famous list of non-cometary deep-sky objects as numbers 81 and 82.

A century before Bode's discoveries, astronomers such as John Flamsteed (1646–1719) in England and Christiaan Huygens (1629–1695) in the Netherlands had struggled with monster refracting telescopes of immense length. Two problems such instruments encountered were the poor quality of glass and the grinding techniques employed. No matter how hard telescope makers tried, color fringes around bright objects plagued them. Opticians call this defect chromatic aberration.

To help mitigate this problem, refracting telescopes had become incredibly long because lenses with long focal lengths reduce the color-fringe effect. By the time Bode was hard at



This photograph of M81 was the best image anyone had when astronomers at Lick Observatory took it in 1908. Linda Hall Library of Science, Engineering, and Technology



In near-infrared wavelengths, M81 (left) looks like a black-and-white version of Hubble's colorful shot, but M82 loses a lot of its explosive detail and resembles an edge-on spiral. These images primarily reveal the heat-emitting dust these galaxies contain. 2MASS

work, opticians had greatly improved the optics and reduced refractors in length. This gave astronomers better tools with which to roam freely among the stars searching for curiosities.

Bode had suffered from a serious eye disease when he was young, and it's amazing that he made any astronomical discoveries at all. Slightly more than a month after finding M81 and M82, he discovered the globular cluster M53 in Coma Berenices. Today, historians remember Bode mostly for his famous law that described an apparent ratio for the spacing of planets within the solar system.

Scientific setting

Unfortunately, Bode would never know the nature of his finds. The best he could do was describe M81 and M82 as small fuzzy "nebulae." Even in the first part of the 20th century, astronomers were unsure of the true nature of M81 and M82.

The 1881 edition of William H. Smyth's *A Cycle of Celestial Objects*, updated by George F. Chambers, describes M81 as "a bright-class round nebula, at the back of Ursa Major's left ear."

"It is lucid white, and lights up in the center," the book reads. "The sky is intensely black, and shows the nebula as if floating in awful and illimitable space, at an inconceivable distance."

Current measurements place this "inconceivable distance" at 12 million light-years for both M81 and M82. On a cosmic scale, that makes them two of our closest neighbors.

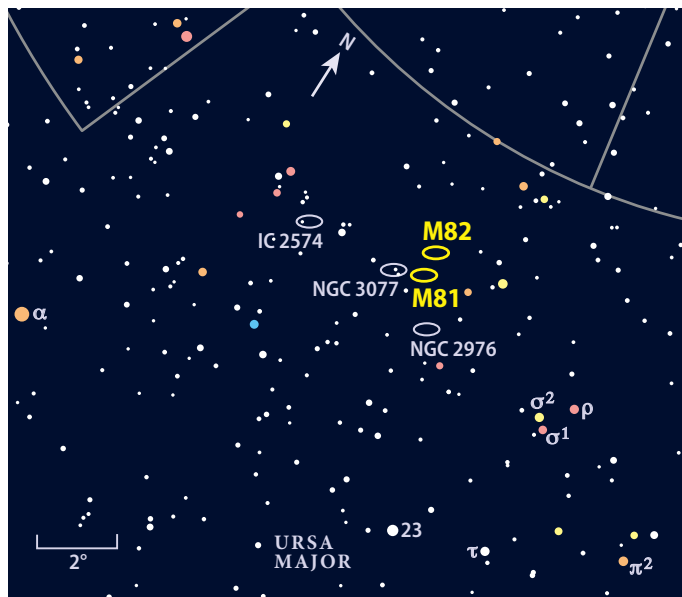
The Milky Way and the Andromeda Galaxy (M31) are the two principal objects in our Local Group of galaxies. This collection contains about three dozen galaxies, mostly small, and measures about 10 million light-years across. The gravitational center of this sphere lies roughly between our galaxy and M31.

Just beyond the fringe of our little neighborhood lies the M81 Group of galaxies, of which the namesake is visually the brightest and most massive. M82 represents the group's other

major component. About a dozen other galaxies, including spirals NGC 2976 and NGC 3077, complete the M81 Group.

In the early 20th century, spiral M81 and irregular M82 represented two of the three basic types of galaxies (along with elliptical galaxies). American astronomer Edwin Hubble (1889–1953) was trying to put some order to the variation on these three basic types and determine how they developed. Hubble created the Tuning Fork diagram to explain how galaxies change and morph over time.

Current theory and observations show that Hubble's basic idea was incorrect. M81 and newly classified starburst galaxy M82 are prime examples of how the gravitational interaction between such objects affects their morphology.



M81 and M82 lie in the northwestern part of Ursa Major the Great Bear. Steadily held binoculars that magnify 10 times will reveal them from a dark site. The other labeled galaxies on this illustration belong to the M81 Group. Astronomy: Richard Talcott and Roen Kelly

Raymond Shubinski is executive director of the Atomic Testing Museum in Las Vegas. He has observed M81 and M82 for more than 3 decades.



A field of view spanning about 1° captures both M81 and M82 in the same image. This image also shows some of the gas gravitationally ejected from the galaxies during their close passage. Dean Salman

In the Local Group, 2.5 million light-years separate the Milky Way and the Andromeda Galaxy. M81 and M82 lie a mere 150,000 light-years apart. Observational evidence also suggests these two galaxies passed even closer to each other in the last few hundred million years. This close encounter has given each galaxy its own set of characteristics.

The beautiful patterns in the spiral arms of Bode's Galaxy are caused by density waves. The arms of a spiral galaxy consist of high- and low-density waves that manifest themselves as regions, which cause stars to clump together. Astronomers see the same effect in Saturn's rings.

M81 also has a supermassive black hole at its core. The black hole's mass equals 70 million Suns, and it spews out energy as it devours matter. Astronomers see the results of this activity as plasma ejected from M81's core at near light-speed.

Nearby M82, on the other hand, sits in contrast to the beauty of M81. High-resolution images of M82 make it appear to be in the process of being blown apart. Here, star formation and star death are happening at a highly accelerated pace.

The recent encounter between M81 and M82 triggered shock waves in the core of M82 that compressed hydrogen clouds into massive fast-burning stars. These stars evolved quickly and exploded as supernovae.

Those supernova events create more shock fronts that trigger even more star formation. The result is a tremendous galactic superwind. Images show glowing gases expanding away

M81 and M82 at a glance

	Bode's Galaxy	The Cigar Galaxy
Object type:	Spiral galaxy	Starburst galaxy
Other designations:	M81, NGC 3031	M82, NGC 3034
Constellation:	Ursa Major	Ursa Major
Right ascension (2000.0):	9h56m	9h56m
Declination (2000.0):	69°04'	69°41'
Size:	21' by 10'	9' by 4'
Magnitude:	6.9	8.4
Distance:	12 million light-years	12 million light-years

from M82 at high velocity 10,000 light-years beyond the core. Although M81 appears visually brighter, M82 outshines every other galaxy in infrared light.

Long-exposure images also show M81 and M82 embedded in a huge cloud of gas with tails and filaments connecting the two galaxies. All of this activity demonstrates the intense gravitational relationship that can occur in neighboring galaxies.

Astronomers have learned a great deal about galaxies by studying the pair Johann Bode discovered in 1774. Although they lie close enough to fit in a wide-field eyepiece, M81 and M82 differ in substantial ways. One is a graceful spiral and the other an energetic star factory. Together, they form one of the sky's great odd couples. ☾



See more images of Bode's Galaxy (M81) and the Cigar Galaxy (M82) at www.Astronomy.com/toc.



Equipment review

iOptron's lightweight mount supports on-the-go observing

Put your favorite small scope on the MiniTower, and let it be your celestial guide. **by Tom Trusock**

Today's visual observers like a good alt-azimuth mount because of its simplicity and portability. Such units are lightweight, yet they can handle heavy telescopes. If they have a draw-back, it's the lack of automatic tracking.

Enter iOptron Corporation's MiniTower. This lightweight, computerized, alt-azimuth drive lets you configure it as either a single- or dual-arm mount. The MiniTower has a manufacturer-stated load capacity of 25 pounds (11.4 kilograms) on one side and 8 pounds (3.6 kg) on the other. The tripod legs are 1.5 inches (38 millimeters) thick and place it at a comfortable height for observing.

First impressions and setup

The mount arrived in two packages: the tripod in one, and the head and accessories in the other. The tripod weighs 13 pounds (5.9 kg), while the case with the

Tom Trusock is a seasoned observer and equipment junkie who observes from Ubly, Michigan.

head and accessories comes in at 29 pounds (13.2 kg).

With today's trend toward trimmed-down basic offerings, I was surprised to see how many accessories iOptron includes with the MiniTower. Aside from the tripod, you'll find a hard case that contains the head with a standard Vixen-compatible saddle, an arm that allows you to mount a counterweight or another Vixen-style saddle (all included), the hand controller, both AC and DC adapters, a CD-ROM, a USB cable, and all other required wiring.

In addition to AC or DC power, the MiniTower can operate on internal batteries. I ran it using both AC and DC power supplies, and both worked well.

Setup is a simple matter and takes only a few minutes. One of the advanced features of the MiniTower is the fine-leveling adjustments found on the tripod below where the head attaches. These give the user the ability to level the mount quickly and easily. With one- and

Specifications

iOptron's MiniTower

Type: Computerized alt-azimuth mount

Resolution: 1"

Payload: 25 pounds (11.4 kg) + 8 pounds (3.6 kg)

Tripod: Aluminum and stainless steel

Database: 130,000 objects

Tripod weight: 13 pounds (5.9 kg)

Case weight (mount, counterweights, and accessories): 29 pounds (13.2 kg)

Included: Two Vixen-style saddles, hand controller, AC and DC adapters, all wiring, CD-ROM, hard case

Price: \$799

two-star alignment methods, a level mount is critical for both accurate pointing and tracking.

The next step is to mount the telescope(s) into the supplied saddle(s). If you're using a single telescope heavier than about 15 pounds (6.8 kg), you'll want to use the included counterweight. This ensures the mount is not off balance — something that can affect performance, stability, and usability.

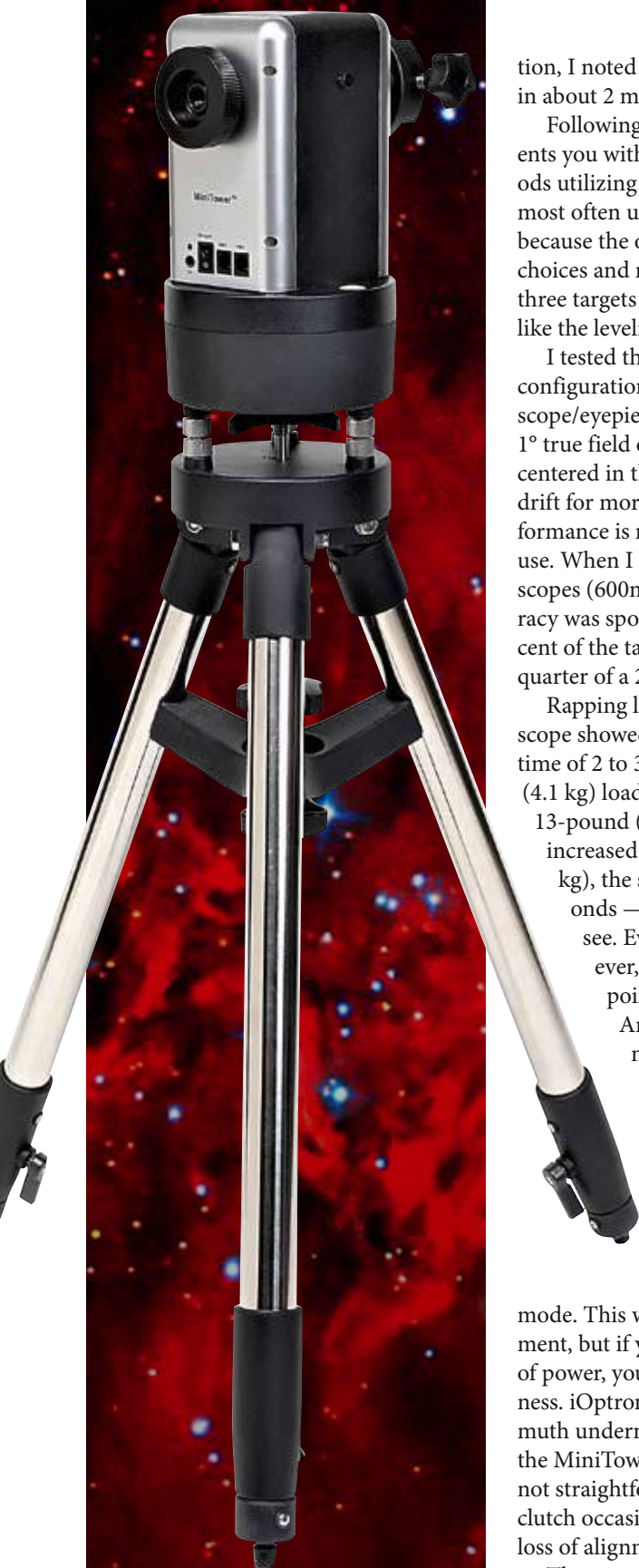
If you're using two scopes side by side, you'll want to take a few minutes to align them. iOptron included a fair amount of play in the mounting for aligning the second telescope, but you may need to shim the scope a bit to get it just right.

Power on!

When I powered on the mount, the GPS refused to lock on. A call to iOptron's technical support helped me locate the problem: a loose antenna, most likely jostled during shipping. Ultimately, it was of little inconvenience because users can enter their own coordinates, local time, and the date. After I fixed the connec-



By adding the stainless steel extension (left), you can mount a second telescope on the MiniTower. Or, if your primary telescope weighs more than about 15 pounds (6.8 kg), use the supplied counterweight for balance. Equipment photos: Astronomy; James Forbes; backgrounds: Tony and Daphne Hallas



iOptron's MiniTower alt-azimuth mount comes with everything you'll need but the telescopes. That's right: telescopes. The MiniTower can drive two scopes at once.

tion, I noted the GPS typically locked on in about 2 minutes.

Following setup, the MiniTower presents you with multiple alignment methods utilizing one, two, or three targets. I most often used the two-star alignment because the one-star method limited the choices and never offered more than three targets to pick from. Alignment, like the leveling, was quick and easy.

I tested the MiniTower under various configurations and loads. With a telescope/eyepiece combination that gave a 1° true field of view, the target remained centered in the field with no detectable drift for more than 30 minutes. Such performance is more than enough for visual use. When I used short focal length scopes (600mm and less), pointing accuracy was spot on, with more than 90 percent of the targets falling in the center quarter of a 2° field.

Rapping lightly on the side of the telescope showed the mount to have a settle time of 2 to 3 seconds under a 9-pound (4.1 kg) load and 3 to 4 seconds under a 13-pound (5.9 kg) load. When I increased the load to 20 pounds (9.1 kg), the settle time went past 5 seconds — longer than what I like to see. Even under heavy loads, however, the mount tracked well and pointing accuracy was excellent. And one more point your neighbors will appreciate at 3 A.M.: The mount was quieter than most other go-to drive systems.

Another nice feature of the MiniTower is that a user can simply loosen the clutches and use the mount in manual mode. This will cause you to lose alignment, but if you're observing and run out of power, you're not totally out of business. iOptron located the clutch for azimuth underneath the head, so adapting the MiniTower head to another tripod is not straightforward. Further, the altitude clutch occasionally disengaged, causing a loss of alignment.

The controller offers a wide selection (some 130,000) of targets. The eight-line screen is large and easy to read, with adjustable settings for brightness and contrast. iOptron also includes a red light on the back of the controller.



The MiniTower and all of its accessories except the tripod fit into a padded case. The hand paddle (right) controls the system.

Another plus of the MiniTower is its ability to work with your personal computer. As of this writing, the planetarium software packages *Cartes du Ciel* and *HN Sky* are compatible with the MiniTower's controller. On the picky side, the MiniTower's software could use some polish. I noted intermittent spelling errors. For example, Jupiter was spelled properly in one menu and as "Jupitre" in another.

Lightweight muscle

Overall, while I wish the mount were a little more solid under heavy loads, the MiniTower is lightweight, extremely portable, and easy to use. It's a good match for small telescopes, and it offers precise tracking and pointing. iOptron includes lots of accessories, so users won't need to purchase much in the way of extras. The ability to mount scopes side by side is a treat — especially for outreach purposes. In short, the MiniTower is worth your consideration if you're looking to lighten your load for "grab-and-go" observing. ☿

Contact information

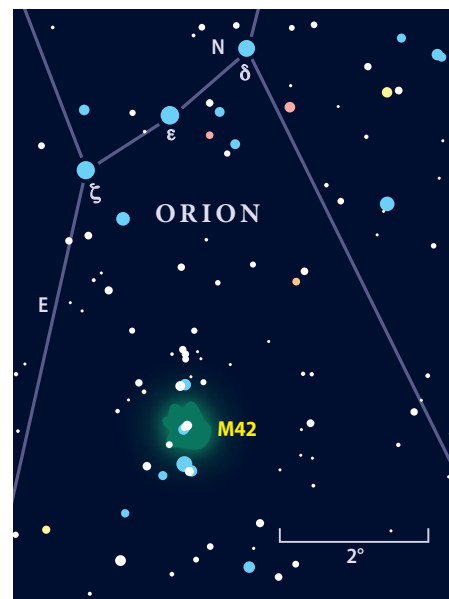
iOptron Corporation
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Woburn, MA 01801
[t] 866.399.4587
[w] www.ioptron.com

When Galileo first pointed his telescope to the sky 400 years ago, the number of previously unseen stars this piece of equipment brought to light astounded him. In *Sidereus Nuncius* ("Starry Messenger," published in 1610), he wrote: "In addition to stars of the sixth magnitude, a host of other stars are perceived through the telescope which escape the naked eye." He realized that they far exceed in number the stars visible to the unaided eye.

Galileo intended to prove this point with a telescopically produced map of the constellation Orion. Encountering far too many stars, he narrowed his focus to Orion's Belt and Sword. To the naked-eye stars already known — three in the Belt and six in the Sword — Galileo was able to add another 80.

Galileo's map, which appears in *Sidereus Nuncius*, covers a 5.5° by 7° area of sky and is shown on this page. Compare it with our modern-day chart that plots stars to a similar limiting magnitude — about 9. Except for the Belt stars, the two don't match very well. Galileo's telescope had an extremely narrow field of view, perhaps less than 0.25°. Making an accurate sky map with such an instrument would be a virtual impossibility.

In addition to the inaccuracies of Galileo's map, you'll notice a major omission. The great Orion Nebula is nowhere to be seen! It's quite likely that as Galileo scanned the stars in Orion's Sword, it slipped unnoticed through the narrow field of his crudely fashioned telescope. Remember, Galileo charted the Belt and Sword to document the existence of stars never before seen by the human eye; he was not trying to discover deep-sky objects. Inaccurate and incomplete though his map may be, it sent out a loud and clear message that there was much yet to be discovered with the telescope.



Using his telescope, Galileo created a map of what he saw in Orion's Belt and Sword (left). But his telescope had a very narrow field of view, which made creating an accurate sky map almost impossible. Our map of the same area therefore is different from Galileo's; it also includes a key feature he missed — the Orion Nebula. Left: Linda Hall Library of Science, Engineering & Technology; right: Astronomy: Roen Kelly

Because today's telescopes are vastly superior to the one Galileo employed, let's use our 21st-century optics to admire what many deep-sky observers consider the night sky's grandest masterpiece.

Visible to the naked eye as a fuzzy "star" in the middle of Orion's Sword, the Orion Nebula is transformed by binoculars or small telescopes into a curious glow surrounding the stars Theta¹ and Theta² Orionis. The view through a large-aperture telescope is breathtaking!

Wreaths of bright gas, pale green in color, radiate outward like eagle's wings to cover an area several times larger than the Full Moon. The sight is both chaotic and tranquil, leaving us gaping in awe.

So overwhelming is the splendor of the Orion Nebula that we often fail to notice a tiny quadrangle of 5th- to 8th-magnitude stars in its midst. This is Theta¹ Orionis, "the Trapezium" — a

delicate stellar quartet whose 21" dimension is equivalent to the apparent size of Saturn's disk. A nest of newborn stars, it illuminates the nebula that spawned it. The Trapezium (at least its three brightest members) was first seen by Galileo in 1617. He missed the body of the Orion Nebula, but found its heart.

If you want to get in the spirit of the International Year of Astronomy 2009, repeat Galileo's exploits and make your own map of Orion's Belt and Sword. But use an instrument that affords a wide field of view — binoculars, perhaps.

The limiting magnitude for standard 7x35 or 7x50 binoculars under average sky conditions falls somewhere between 8th and 9th magnitude — about the same as Galileo's telescope. Compare your finished product with the ones on this page. Hopefully, yours will match our version better than Galileo's! ☛



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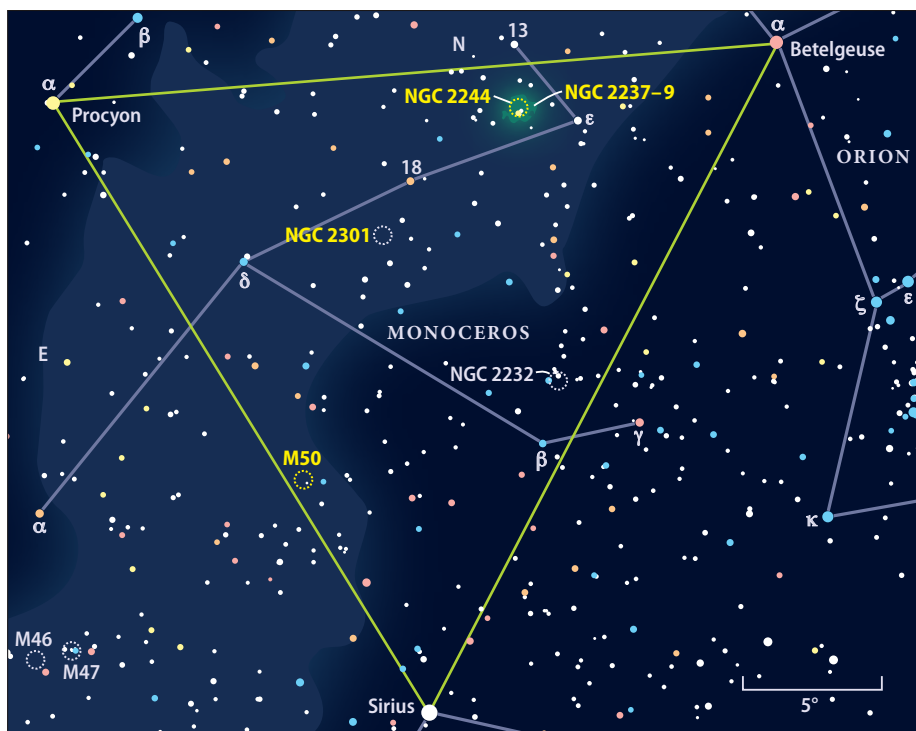
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I've been able to see it faintly through 10x50 binoculars, but my best view came through 16x70s on an especially clear winter's night. The nebula looked like a



If you have questions, comments, or observations to contribute, e-mail me at phil@philharrington.net. Next month, it's time for our annual Messier Bino-Thon. Till then, remember that two eyes are better than one. ☺

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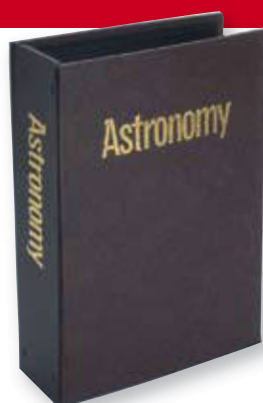
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Awash in color

This stunning combination of blue reflection nebulosity and pink and red emission nebulosity has few rivals in the autumn sky. Two reflection nebulae lie near the image's center. NGC 6914 (left) is the largest. At dead-center is NGC 6914A. Open cluster Dolidze 8 — enveloped by reflection nebula NGC 6914B — floats to the upper-right of center. The background field is aglow with unnamed emission nebulosity.

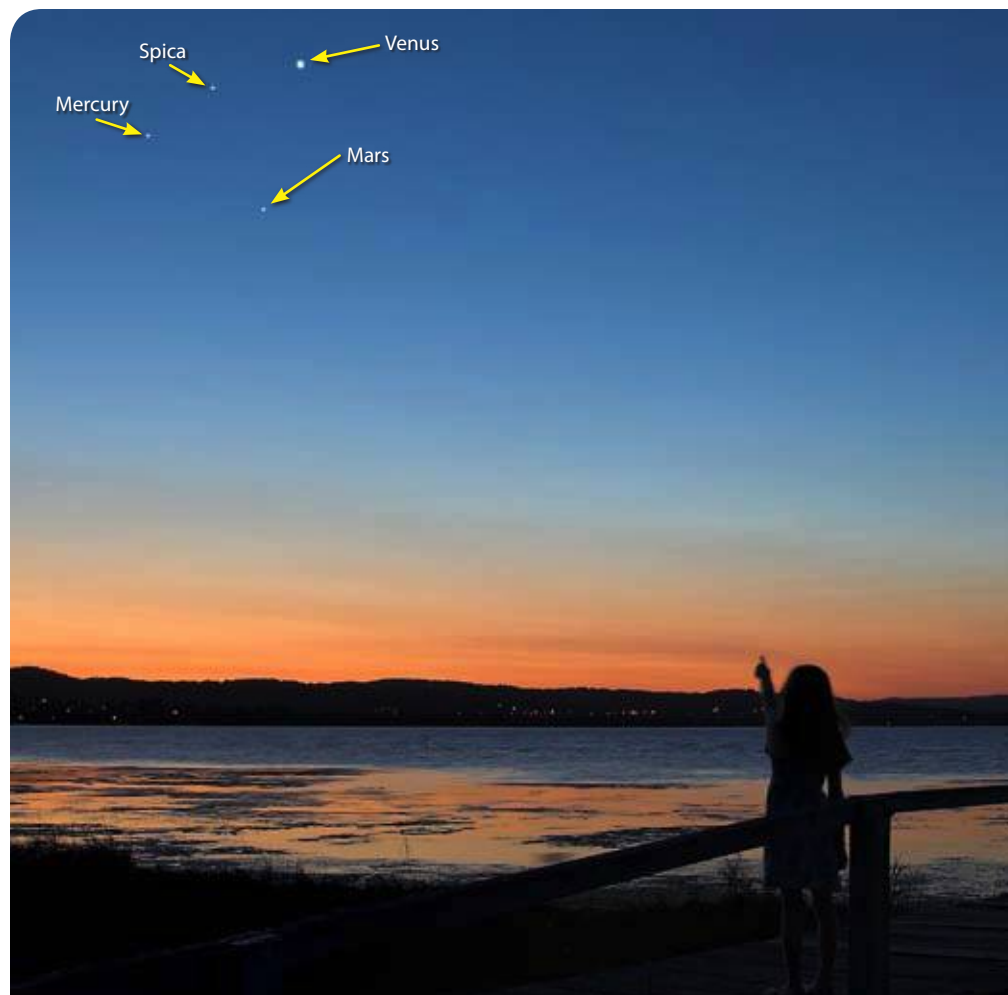
NGC 6914 (12.5-inch homemade Newtonian reflector at f/5, Santa Barbara Instrument Group ST-10XME CCD camera, LRGB image with exposures of 120, 40, 40, and 40 minutes, respectively) • Chris Schur, Payson, Arizona



The Sculptor Galaxy (NGC 253) drifts alone through a sparse starry background in the constellation Sculptor. The galaxy shines at magnitude 7.3. (4-inch Takahashi FSQ-106 apochromatic refractor at f/5, Canon 20DA digital SLR, a combination of three 10-minute images) • Bill Drelling, Alameda, California



Few images of partial lunar eclipses captivate amateur astronomers. This series, however, conveys the sense that the Moon is passing through Earth's shadow. (6.4-inch Astro-Physics AP 160 StarFire EDF apochromatic refractor at f/7.5, Canon EOS 300D digital SLR, ISO 200, nine exposures ranging from $\frac{1}{250}$ to $\frac{1}{30}$ second, taken August 16, 2008, from 19:30 UT to 22:50 UT) • Anthony Ayiomamitis, Athens, Greece

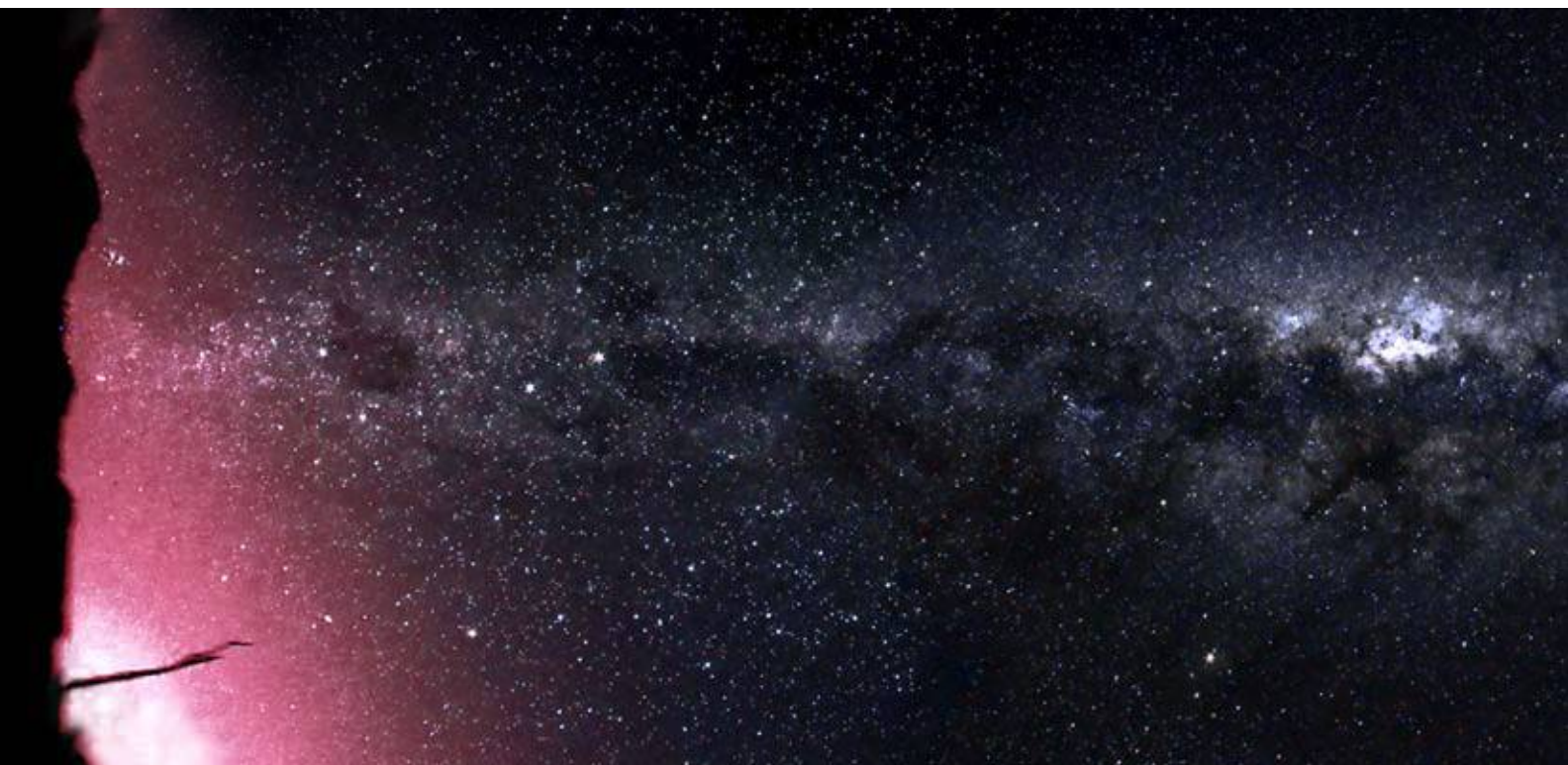


< Venus, Mercury, and Mars met in Virgo near that constellation's brightest star, Spica, last September. (Canon 350D digital SLR, Sigma 17-70mm lens at f/7.1, ISO 100, 1.6-second exposure taken September 20, 2008, from Long Jetty, New South Wales, Australia)
• Mike Salway, Wyoming, Australia

> The constellation Cepheus is full of colorful stars. One of the sky's reddest stars — Herschel's Garnet Star (Mu [μ] Cephei) lies at bottom center. Numerous nebulae also fill the scene. (Guided exposure with a special filter that slightly diffuses the bright star images) • Bill and Sally Fletcher, Little River, California

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▲ **The southern Milky Way** reveals lots of detail in this wide-field image. Sagittarius dominates the center of this shot, while Alpha (α) and Beta (β) Centauri point to Crux near the left edge. (Canon EOS 30D digital SLR, Canon EF f/2.8 14mm lens at f/8, ISO 1600, five 263-second exposures) • **Alberto Geyer and Eduardo Cidade, Muri, Brazil**

➤ **This bubble-shaped nebula** in Cygnus was discovered independently by amateur astronomers — Dave Jurasevich July 6, 2008, and then Keith Quattrocchi and Mel Helm July 17, 2008. Jurasevich has submitted his discovery to the International Astronomical Union for designation. (16-inch RC Optical Systems Ritchey-Chrétien telescope at f/9, SBIG STL-6303M CCD camera, H α /SII/OIII image with twenty-one 20-minute exposures through each filter for a total exposure time of 21 hours) • **Keith Quattrocchi, Clovis, California**



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▲ **This Moon mosaic** required 16 video sequences of approximately 300 images each merged into 16 final images, which then became a Full Moon. (3.6-inch Meade ETX-90EC Maksutov-Cassegrain telescope at f/13.8, ToUcam Pro webcam, taken March 21, 2008, between 10:39 P.M. and 11:00 P.M. from Sabreda, Portugal) • [Miguel Claro, Corroios, Portugal](#)

➤ **Emission nebula Cederblad 90** in Monoceros lies at the southern tip of the Seagull Nebula (IC 2177). You'll find it 2.3° south-southeast of M50. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/5.5, SBIG ST-10XE CCD camera, LRGB image with exposures of 90, 20, 20, and 20 minutes, respectively) • [Tad Denton/Adam Block/NOAO/AURA/NSF](#)





Spiral galaxy NGC 5907 in Draco lies approximately 39 million light-years from Earth. The faint, looping contrails this image reveals arose when NGC 5907 disrupted a former small satellite galaxy and probably absorbed it.

(20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8, SBIG STL-11000 CCD camera, LRGB image with exposures of 465, 120, 72, and 144 minutes, respectively) • **R. Jay GaBany, San Jose, California**

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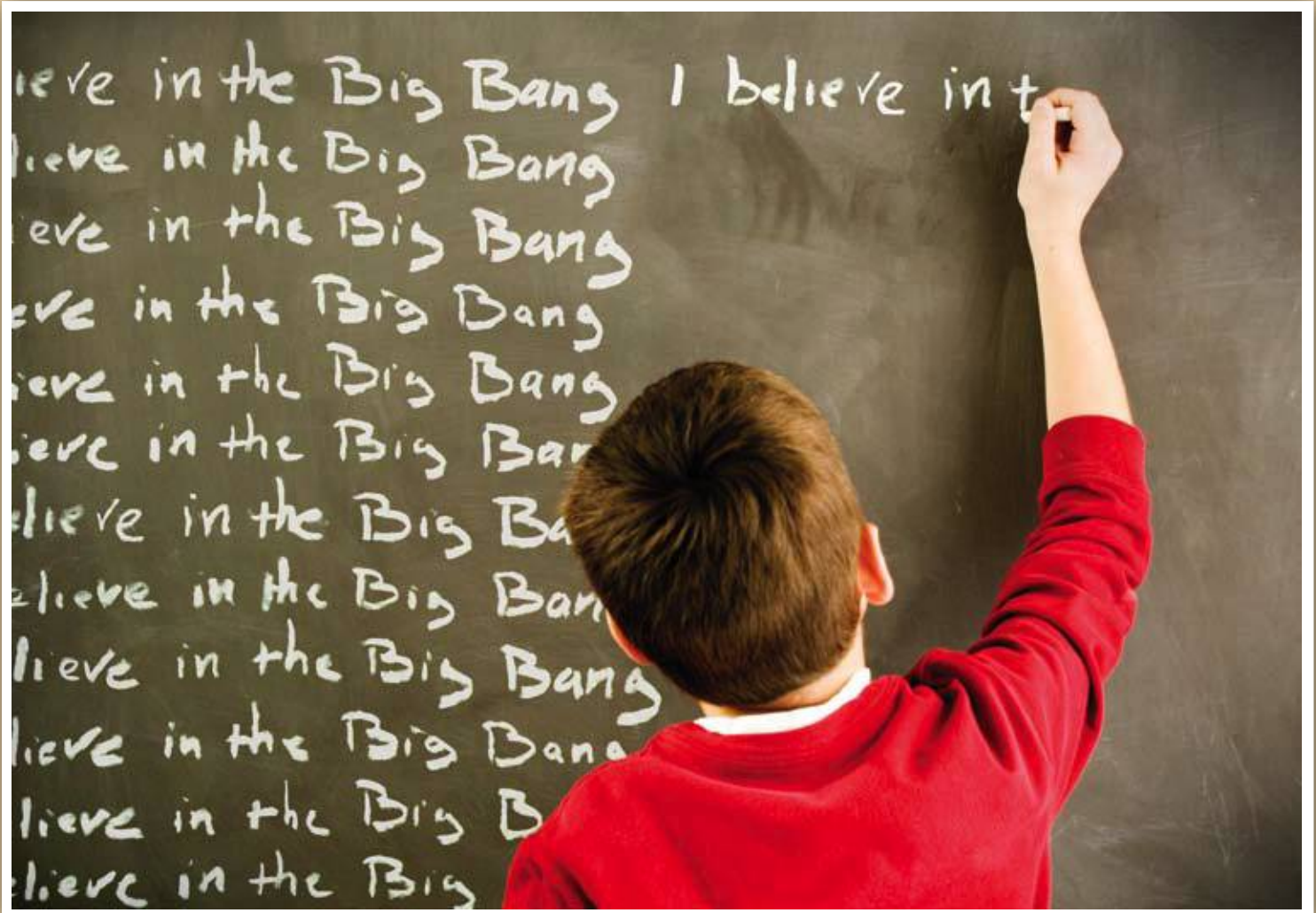
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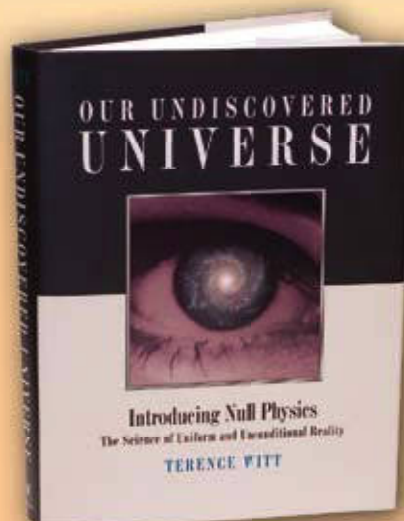
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